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RELIABILITY/MAINTAINABILITY/ TESTABILITY DESIGN FOR DORMANCY

Lockheed Electronics Company, Inc.

Robert M. Seman, Julius M. Etzl and Arthur W. Purnell

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This document has been prepared as a tool for designers of dormant military equipment and systems. The purpose of this handbook is to provide design engineers with Reliability/Maintainability/Testability design guidelines for systems which spend significant portions of their life cycle in a dormant state. The dormant state is defined as a nonoperating mode where a system experiences very little or no electrical stress.

The guidelines in this report present design criteria in the following categories: (1) Part Selection and Control; (2) Derating Practices; (3) Equipment/System Packaging; (4) Transportation and Handling; (5) Maintainability Design; (6) Testability Design; (7) Evaluation Methods for In-Plant and Field Evaluation; and (8) Product Performance Agreements. Whereever applicable, design guidelines for operating systems were included with the dormant design guidelines. This was done in an effort to produce design guidelines for a more

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complete life cycle. Although dormant systems spend significant portions of their life cycle in a nonoperating mode, the designer must design the system for the complete life cycle, including nonoperating as well as operating modes.

The guidelines are primarily intended for use in the design of equipment composed of electronic parts and components. However, they can also be used for the design of systems which encompass both electronic and nonelectronic parts, as well as for the modification of existing systems.

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1.0 INTRODUCTION

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The guidelines in this report present design criteria in the following categories:

1. Part Selection and Control
2. Derating Practices
3. Equipment/System Packaging
4. Transportation and Handling
5. Maintainability Design
6. Testability Design
7. Evaluation Methods for In-Plant and Field Evaluation
8. Product Performance Agreements

Wherever applicable, design guidelines for operating systems were included with the dormant design guidelines. This was done in an effort to produce design guidelines for a more complete life cycle. Although dormant systems spend significant portions of their life cycle in a nonoperating mode, the designer must design the system for the complete life cycle, including nonoperating as well as operating modes.

The guidelines are primarily intended for use in the design of equipment composed of electronic parts and components. However, they can also be used for the design of systems which encompass both electronic and nonelectronic parts, as well as for the modification of existing systems.

1.1 THE NEED FOR DORMANCY DESIGN GUIDELINES

The nonoperating modes include: dormant storage, captive carry, ready alert, or other dormant states. After equipment has been installed in the field or stored in arsenals and the supporting spares stored in warehouses, the military has recognized that the dormant mode is a predominant portion of the life cycle of military equipment.

Subsequently, the dormant effects on electronic equipment and reliability is of significant importance. The dormant mode and dormancy effects are not always considered during the design phases because sufficient dormant design information is not readily available to the design engineer. This document has been prepared to present design guidelines to mitigate the effects of the dormant environment on electronic equipment. These design guidelines present design considerations which will improve the reliability, maintainability, and testability of dormant systems.

1.2 THE GUIDELINE DEVELOPMENT PROGRAM

The development of design guidelines for dormant systems was divided into four phases:

Phase I - Data Collection
Phase II - Data Analysis
Phase III - Design Guideline Development
Phase IV - Design Guideline Documentation

In the first phase, information on dormancy and existing dormant system design guidelines were collected from four primary sources.

The first source was a literature search of documents containing relevant information. Three hundred and seventeen (317) documents that contain information relevant to the development of dormant system design guidelines were collected.

The second source was a survey of Qualified Parts List (QPL) Vendors to determine information on the effects of various dormant environments on military components, and also to determine any guidelines for using these components in dormant systems subjected to various environments.

The third source was a survey of government agencies and contractors to identify experience with dormant systems, and to identify any guidelines that were used in the development of these systems.

The fourth source was an analysis of various dormant military systems to determine design criteria and dormant experiences of these systems. Documents containing dormancy information for these systems and personnel with additional information were identified. Pertinent system documents were obtained and additional information was obtained from the identified personnel.

In addition to these four primary sources of information, additional personnel were identified and contacted. Meetings were held and relevant conferences were attended in order to obtain dormancy information.

From these sources data was collected that contained information on dormancy, dormancy associated problems, dormant design considerations, and unique modes associated with dormancy. Data on the environments experienced by dormant systems and components, the effects of these environments on dormant systems and components, Reliability/Maintainability/Testability history and design considerations, and guarantee/warranty/incentive programs for dormant systems was collected.

In the second phase the data collected in Phase I was analyzed to identify information that was pertinent to this program. The analyzed information from the sources was entered into the databases and/or documented for subsequent design guideline development. The analyzed data was classified by environmental factors, maintenance and testabilty concepts, and design guideline categories.

In the third phase Reliability/Maintainability/Testability design guidelines were developed for designing systems which spend significant portions of their life cycle in a dormant state. The guidelines present design criteria in the following categories:

1. Part Selection and Control
2. Derating Practices
3. Equipment/System Packaging
4. Transportation and Handling
5. Maintainability Design
6. Testability Design
7. Evaluation Methods for In-Plant and Field Evaluation
8. Product Performance Agreements

In the fourth phase, the design guidelines developed in the third phase were documented in the format presented in this volume of the report. In volume 2 of this report, the four phases of this project are discussed in greater detail.

2.0 HOW TO USE THESE GUIDELINES

To assist the user in locating information, this report has been divided into the following major sections:

3. Dormancy Environments

4. Design Guidelines

    4.1 Part Selection/Control
    4.2 Derating
    4.3 Maintainability Design
    4.4 Testability Design
    4.5 Packaging
    4.6 Transportation and Handling

5. Evaluation Methods

6. Product Performance Agreements

    Appendices

    - Reliability Checklist
    - Testability Checklist
    - Maintainability Checklist

Each section is formatted to include a summary of problems encountered in the dormant mode, some background information, and the guidelines for dormant systems. The guidelines recommend design criteria, tradeoff methodologies, and special design tasks for dormant systems. Figures and tables in each section summarize and supplement the guidelines.

The checklists provided in the appendices present to the designer a quick method for checking the reliability/maintainability/testability requirements of the dormant system.

Wherever applicable, significant design guidelines for operating systems were included with the dormant design guidelines.

Section 3, Dormancy Environments presents information on the predominant environments encountered by dormant systems. This section also contains basic guidelines for protecting equipment from these environments.

Section 4.1, Part Selection/Control presents design guidelines for selecting and designing with the following component types when used in a dormant environment:

- 4.1.1 Resistors
- 4.1.2 Capacitors
- 4.1.3 Microcircuits
- 4.1.4 Semiconductors
- 4.1.5 Inductive Devices
- 4.1.6 Relays
- 4.1.7 Switches
- 4.1.8 Connectors
- 4.1.9 Cables
- 4.1.10 Batteries
- 4.1.11 Fiber Optics
- 4.1.12 Quartz Crystals
- 4.1.13 Electromechanical Devices
- 4.1.14 Packaging Electronic Components for Long Term Storage

Section 4.2, Derating, presents derating criteria for components in a dormant mode.

Sections 4.3 and 4.4, Maintainability and Testability Design, present design guidelines for maintainability and testability of dormant systems.

Section 4.5, Packaging, presents guidelines for protecting dormant equipment from various environmental factors.

Section 4.6, Transportation and Handling, presents design guidelines for these phases of the life cycle.

Section 5, Evaluation Methods, presents design guidelines for in-plant and field evaluation methods for dormant systems.

Section 6, Product Performance Agreements, provides design guidelines for the selection and application of product performance agreements for dormant systems.

3.0 DORMANCY ENVIRONMENTS

3.1 SYSTEM LIFE CYCLE PROFILE

The life cycle of military equipment can be divided into 8 phases:

1. design and development
2. production
3. acceptance and evaluation testing
4. packaging
5. transportation
6. dormant nonoperational modes (storage, ready alert, etc.)
7. pre-operation testing
8. operation/use

These phases are illustrated in figure 3.1-1.

In designing and developing military systems it is vitally important that the system life cycle be thoroughly understood. While the life cycle presented in figure 3.1-1 encompasses every major step in the development and use of a typical military system from concept to final operation, the actual phases and sequence for a specific system will depend upon its design characteristics and intended use. For example, reusable equipment will generally experience the latter phases of the life cycle repetitively, whereas, expendable (e.g., one-shot) equipment will generally experience a less repetitive life cycle, spend more time in a non-operational phase, and have its life cycle terminated by its operation/use.

In addition to understanding the life cycle of a system, the designer must also understand and consider the effects of the various environmental factors that the system will be subjected to throughout its life cycle. Equipment in the procurement and production stages, the first four stages of the life cycle, generally does not experience degrading environments for any significant periods of time. After issue, however, the final stages of the life cycle are experienced and

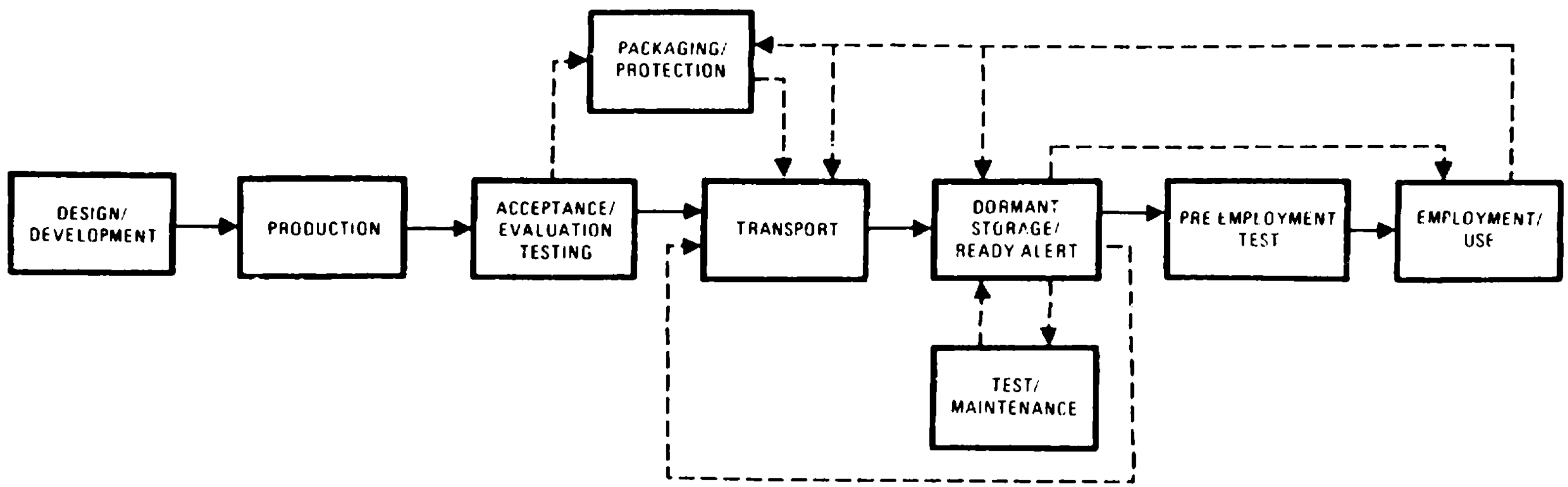


Figure 3.1-1. Typical Dormant System Life Cycle Profile

the equipment is exposed to a variety of potentially degrading environmental factors for extended periods of time. The importance of these environmental factors during pertinent life cycle stages is illustrated in Table 3.1-1.

Most military equipment is not used immediately after issue, but rather must await the proper circumstances before its use. Generally, it is placed in a non-operational (dormant) mode before and between use. These non-operational modes may be storage or ready alert configurations, or non-operating periods during use such as unpowered space flight or standby redundant equipment. Table 3.1-2 identifies typical non-operating modes for military equipment.

Dormancy and its effect on system reliability should be a primary concern during the design and development of military systems. Systems put into use after extended periods of dormancy must perform without mission degrading malfunctions. Dormancy in many systems, such as missiles and munitions, is a particular concern because these systems spend the majority of their life in a non-operating (e.g., storage, ready alert, captive carry, etc.) mode. For example, in a typical missile system the non-operating time could be as much as two million times longer than operating time. Although the operating failure rate may be substantially greater than the non-operating failure rate, the significant difference in time between these two states makes dormancy a major factor to consider. (Ref. 17)

The following sections describe the primary degrading environments that may be encountered by systems during dormant periods. Also presented are basic design guidelines that will assist the design engineer in designing adequate protection to mitigate the effects of these environments. Subsequent sections of this report provide more detailed guidelines for designing military systems that will spend significant portions of their life in dormant modes.

3.2 ENVIRONMENTAL CONSIDERATIONS

This section describes the environmental conditions that a dormant system may be subjected to throughout its life cycle. Essentially, the environmental factors can be classified into two groupings: the natural environment and the induced (man-made) environments. The natural and induced environments are important because of their effects on equipment. Principal effects and types of failures induced by various environmental factors are listed in Table 3.2-1. (Refs. 4, 5, 6.)

Table 3.1-1. Association of Factor Importance with Equipment Life Cycle Stage. (Ref. 11)

Equipment Life Cycle Stage	Environmental Factor: Temperature	Humidity	Pressure	Solar radiation	Rain	Solid Precipitation	Fog	Wind	Salt	Fungus	Atmospheric pollutants	Sand and dust	Vibration	Shock	Acceleration	Acoustics	Electromagnetic radiation	Nuclear radiation
Dormant Storage	A	A	C	O	O	O	O	O	C	B	C	C	C	B	O	O	O	O
Transportation																		
Highway	B	B	O	C	B	B	B	C	O	O	O	C	A	A	C	O	O	O
Rail	B	B	O	C	C	B	C	C	O	O	O	C	A	A	C	O	O	O
Ship	C	B	O	C	C	O	B	C	B	O	O	O	B	C	C	O	O	O
Air	B	O	C	O	C	C	A	B	O	O	O	C	B	B	B	O	O	O
Operational Use																		
Cold Regions	A	A	O	B	A	A	B	B	C	O	C	C	B	B	O	C	B	C
Hot-Wet	A	A	C	B	A	O	O	B	B	A	O	O	B	B	O	C	B	C
Hot-Dry	A	O	O	A	O	O	O	B	B	O	O	A	B	B	O	C	B	C
Temperate	A	A	C	B	A	B	B	B	B	B	C	B	B	B	O	C	B	C
Indoor Use	B	B	O	O	O	O	O	O	O	C	C	B	C	O	O	O	B	C
Ready Alert	A	A	O	B	B	B	O	C	B	B	C	C	O	C	O	O	C	C

A - Major Importance
B - Important
C - Minor
O - Absent

Table 3.1-2. *Typical Military Equipment (Non-Operating Modes)*

A. Storage

A1	Dump Storage (open field storage)	-	Uncovered/Unprotected
A2	Dump Storage (open field storage)	-	Covered/Protected
A3	Magazine Storage	-	Shed
A4	Magazine Storage	-	Concrete Magazine without Earth Covering
A5	Magazine Storage	-	Concrete Magazine with Earth Covering
A6	Surface Ship	-	Cargo Bay/Hold
A7	Surface Ship	-	On Deck
A8	Submarine		
A9	Warehouse	-	Controlled Environment
A10	Warehouse	-	Uncontrolled Environment

B. Ready Alert

B1	Ground Fixed	-	Unsheltered
B2	Ground Fixed	-	Sheltered/Controlled Environment
B3	Ground Fixed	-	Sheltered/Uncontrolled Environment
B4	Ground Mobile	-	Unsheltered
B5	Ground Mobile	-	Sheltered/Controlled Environment
B6	Ground Mobile	-	Sheltered/Uncontrolled Environment
B7	Surface Ship	-	Unsheltered
B8	Surface Ship	-	Sheltered
B9	Submarine	-	Inhabited
B10	Submarine	-	Uninhabited/Inside Hull
B11	Submarine	-	Uninhabited/Outside Hull
B12	Naval Undersea	-	Unsheltered
B13	Aircraft Uninhabited	-	Cargo
B14	Aircraft Uninhabited	-	Trainer
B15	Aircraft Uninhabited	-	Bomber
B16	Aircraft Uninhabited	-	Attack

Table 3.1-2. Typical Military Equipment (Non-Operating Modes) (Continued)

B. Ready Alert (Continued)

B17	Aircraft Uninhabited	-	Fighter
B18	Aircraft Inhabited	-	Cargo
B19	Aircraft Inhabited	-	Trainer
B20	Aircraft Inhabited	-	Bomber
B21	Aircraft Inhabited	-	Attack
B22	Aircraft Inhabited	-	Fighter
B23	Aircraft	-	Captive Carry
B24	Aircraft	-	Rotary Winged
B25	Manpack		

C. Miscellaneous

C1	Unpowered Space Flight
C2	War Games
C3	Cannon Launch
C4	Unpowered Standby/Redundant Equipment

Table 3.2-1. Environmental Effects on Materials.

Factor	Principal Effects	Typical Failures Induced
High temperature	Thermal aging:	Insulation failure:
	Oxidation Structural change Chemical reaction	Alteration of electrical properties, discoloration, cracking, crazing
	Softening, melting and sublimation	Structural failure
	Viscosity reduction and evaporation	Loss of lubrication properties
	Physical expansion	Structural failure Increased mechanical stress Increased wear on moving parts
	Differential expansion of dissimilar materials	Binding of parts Packaging distortion/deterioration Seal/gasket distortion/permanent set Electronic circuit instability

Note: In general, the following terms may be applied principally to semiconductors and dielectrics:

- Alteration of electrical properties - increase or decrease of dielectric constant.
- Loss of electrical properties - decrease of dielectric constant to the extent that the material fails to serve its design function.
- Loss of electrical strength - breakdown of arc-resistance.

Table 3.2-1. Environmental Effects on Materials. (Continued)

Factor	Principal Effects	Typical Failures Induced
Low temperature	Increased viscosity and solidification	Loss of lubrication properties
	Ice formation	Alteration of electrical properties
	Embrittlement	Loss of mechanical strength* Cracking, fracture Crazing, hardening Fatique in restrained glass Stiffening of shock mounts
	Physical contraction	Structural failure Increased wear on moving parts
High relative humidity	Moisture absorption	Swelling, rupture of container Physical breakdown Loss of electrical strength
	Chemical reaction: Corrosion Electrolysis	Interference with function Loss of electrical properties Increased conductivity of insulators
	Oxidation	Breakdown of organic surface coatings, Degradation of image transmission through glass or plastic elements, Accelerated biological activity, Deterioration of hydroscopic materials

* This is not true for metals. Low temperature raises strength and stiffness but reduces deformation and toughness.

Table 3.2-1. Environmental Effects on Materials. (Continued)

Factor	Principal Effects	Typical Failures Induced
Low relative humidity	Desiccation:	Loss of mechanical strength
	Embrittlement Granulation	Structural collapse Alteration of electrical properties, "dusting"
High pressure	Compression	Structural collapse Penetration of sealing Interference with function
Low pressure	Expansion	Fracture of container, Explosive expansion, Leakage of gases/fuels, Change in physical/chemical properties of low-density materials, Evaporation of lubricants
	Outgassing	Alteration of electrical properties Loss of mechanical strength
	Reduced dielectric strength of air	Insulation breakdown and arcover Corona and ozone formation
Solar radiation	Actinic and physicochemical reactions:	Surface deterioration Alteration of electrical properties:
	Embrittlement	Discoloration of materials Ozone formation
	Weakening of glued parts/solder joints	Change in strength and elasticity Loss of seal integrity
	Characteristic changes in elastomers and polymers	Softening of potting compounds

Table 3.2-1. Environmental Effects on Materials. (Continued)

Factor	Principal Effects	Typical Failures Induced
Sand and dust	Abrasion	Increased wear Erosion of surfaces
	Clogging	Interference with function Alteration of electrical properties Clogging of openings and air filters
	Chemical reaction	Corrosion through interaction with water
Salt spray	Chemical reactions:	Increased wear Loss of mechanical strength
	Corrosion	Alteration of electrical properties Interference with function
	Electrolysis	Surface deterioration Structural weakening Increased conductivity Production of conductive coatings Corrosion of insulating materials and metals
Wind	Force application	Structural collapse Interference with function Loss of mechanical strength
	Deposition of materials	Mechanical interference and clogging Abrasion accelerated;
	Heat loss (low velocity)	Accelerate low-temperature effects
	Heat gain (high velocity)	Accelerate high-temperature effects

Table 3.2-1. Environmental Effects on Materials. (Continued)

Factor	Principal Effects	Typical Failures Induced
Rain	Physical stress	Structural collapse Added weight
	Water absorption and immersion	Increase in weight Aids heat removal Electrical failure Structural weakening
	Water absorption/freezing	Deterioration/malfunction due to swelling and cracking of parts
	Erosion	Remove protective coatings Structural weakening Surface deterioration
	Corrosion	Enhance chemical reactions Promotes fungal growth
Blowing snow	Abrasion Clogging	Increased wear Interference with function
Temperature shock	Mechanical stress	Structural collapse or weakening Seal damage Shattering of glass/optical equipment Cracking/bridging of surface coatings Cracking of component packages
High speed particles (nuclear irradiation)	Heating	Thermal aging Oxidation
	Transmutation and ionization	Alteration of chemical, physical and electrical properties Production of gases and secondary particles

Table 3.2-1. Environmental Effects on Materials. (Continued)

Factor	Principal Effects	Typical Failures Induced
Zero gravity	Mechanical stress	Interruption of gravity-dependent functions
	Absence of convection cooling	Aggravation of high-temperature effects
Ozone	Chemical reactions	Rapid oxidation
	Crazing, cracking Embrittlement Granulation	Alteration of electrical properties Loss of mechanical strength Interference with function
	Reduction dielectric strength of air	Insulation breakdown and arcover
Explosive decompression	Severe mechanical stress	Rupture and cracking Structural collapse
Dissociated gases	Chemical reactions	Alteration of physical and electrical properties
	Contamination	
	Reduced electrical strength	Insulation breakdown and arcover
Acceleration	Mechanical stress	Structural collapse Leakage of seals

Table 3.2-1. Environmental Effects on Materials. (Continued)

Factor	Principal Effects	Typical Failures Induced
Vibration	Mechanical Stress	Loss of mechanical strength Interference with function Increased wear Seal deformation Optical misalignment
	Fatigue	Structural collapse
Magnetic fields	Induced magnetization	Interference with function Alteration of electrical properties Induced heating
Acoustic noise	Mechanical stress	Failures in lead wires, optical elements, printed circuit boards, and parts Chafing of wires
Fungus	Material reactions	Deterioration of cellulosic materials, hydrocarbons, leather, certain polyurethanes, plastics, PVC formulations, and paints

3.2.1 Natural Environmental Factors

The natural environment consists of the following general elements:

1. Climate - temperature, humidity, pressure and precipitation
2. Solar radiation
3. Sand and dust
4. Wind loading (Table 3.2.1-1)
5. Fungus
6. Ozone
7. Salt Atmosphere
8. Space

3.2.2 Climate

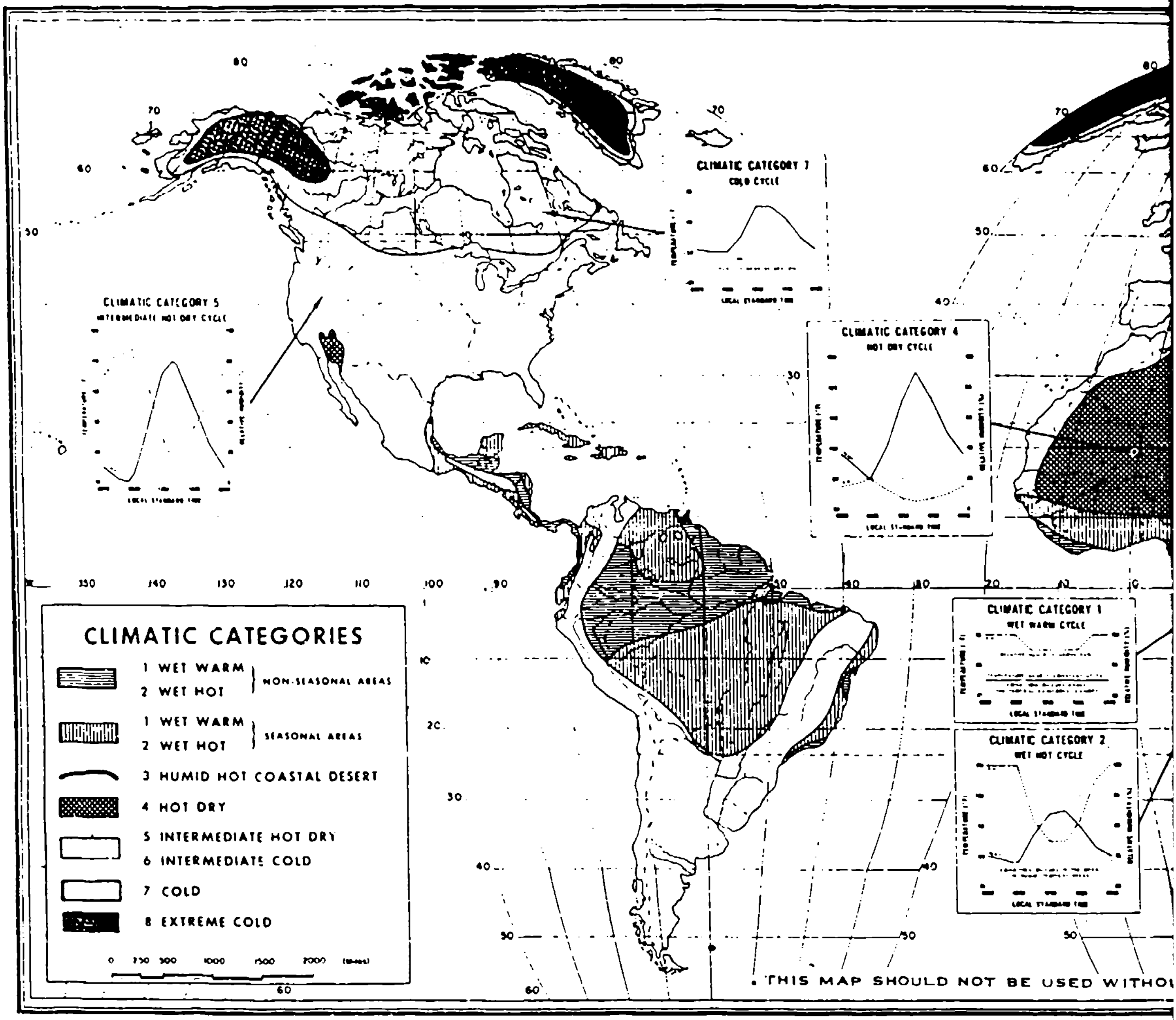
MIL-STD-210, Reference 8, indicates the probable extreme climatic conditions of the natural environment to which military equipment may be exposed, and provides tabular presentation of world-wide climate. MIL-STD-210 classifies the land and surface areas of the world into four regional land type environments and one sea surface and coastal area. AR 70-38, Reference 9, provides a classification system for climate. The system establishes four broad types of climate which are subdivided into a total of eight climatic categories.

These types and categories of climate are identified in Table 3.2.2-1. Figure 3.2.2-1 shows the geographic distribution of the eight climatic categories of climatic design types on a map of the world. For each category, the range of temperature and humidity is indicated. Table 3.2.2-2 summarizes the temperature, solar radiation, and relative humidity, diurnal extremes for the AR 70-38 categories.

AR 70-38 provides detailed coverage of the climates experienced around the world. The climates in these references are listed in the categories identified in Table 3.2.2-1.

Table 3.2.1-1. Beaufort Scale of Wind Force with Velocity Equivalents.

Beaufort Number	Beaufort Descriptive Term	Velocity, mph
0	Calm	Less than 1
1	Light Air	1 to 3
2	Light Breeze	4 to 7
3	Gentle Breeze	8 to 12
4	Moderate Breeze	13 to 18
5	Fresh Breeze	19 to 24
6	Strong Breeze	25 to 31
7	Moderate Gale	32 to 38
8	Fresh Gale	39 to 46
9	Strong Gale	47 to 54
10	Whole Gale	55 to 63
11	Storm	64 to 72
12	Hurricane	73 to 82
13	Hurricane	83 to 92
14	Hurricane	93 to 103
15	Hurricane	104 to 114
16	Hurricane	115 to 125
17	Hurricane	126 to 136



CLIMATIC CATEGORIES
1 WET WARM
2 WET HOT
NON-SEASONAL AREAS
1 WET WARM
2 WET HOT
SEASONAL AREAS
3 HUMID HOT COASTAL DESERT
4 HOT DRY
5 INTERMEDIATE HOT DRY
6 INTERMEDIATE COLD
7 COLD
8 EXTREME COLD
CLIMATIC CATEGORY 7
COLD CYCLE
CLIMATIC CATEGORY 5
INTERMEDIATE HOT DRY CYCLE
CLIMATIC CATEGORY 4
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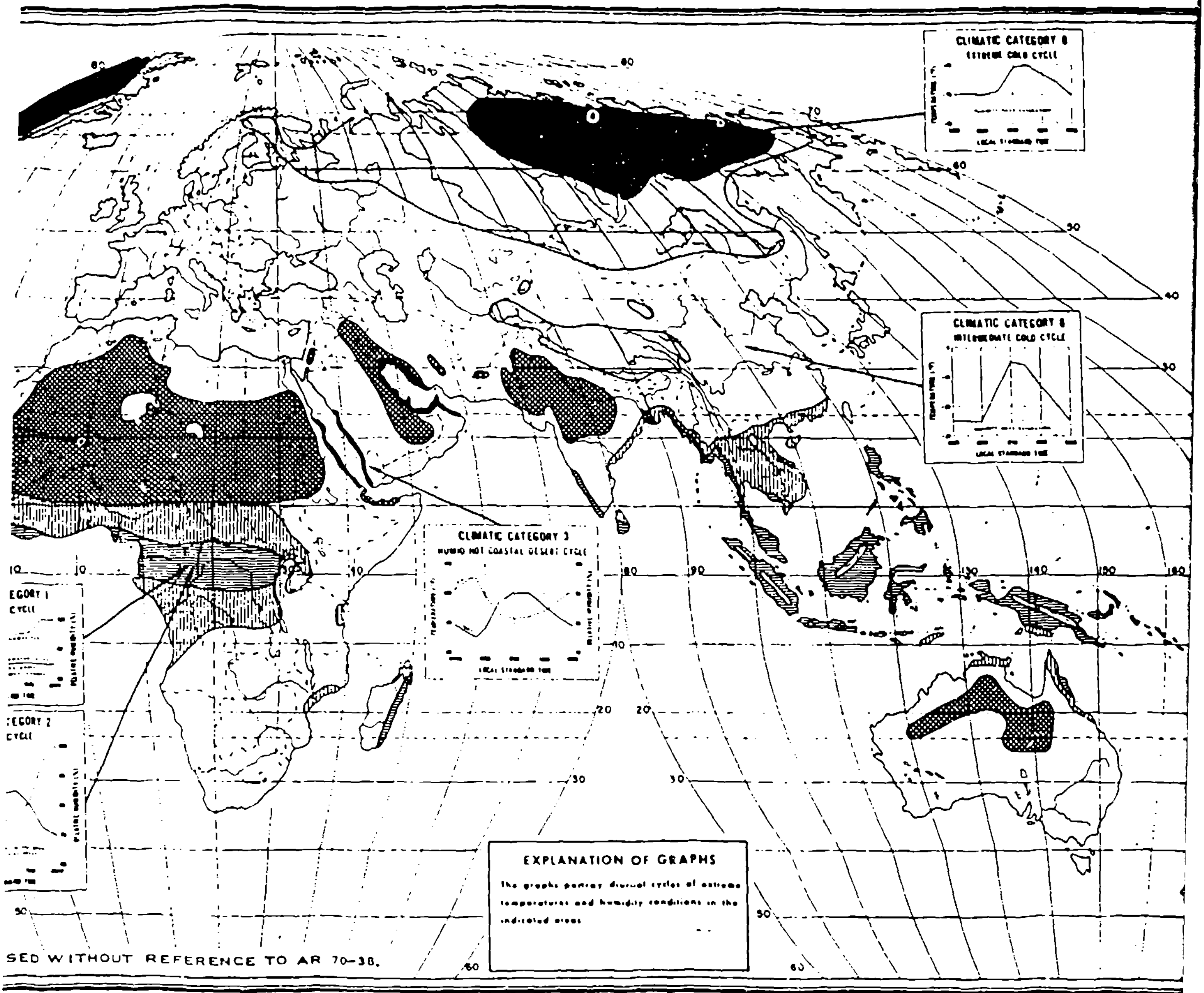

Figure 3.2.2-1. Geo
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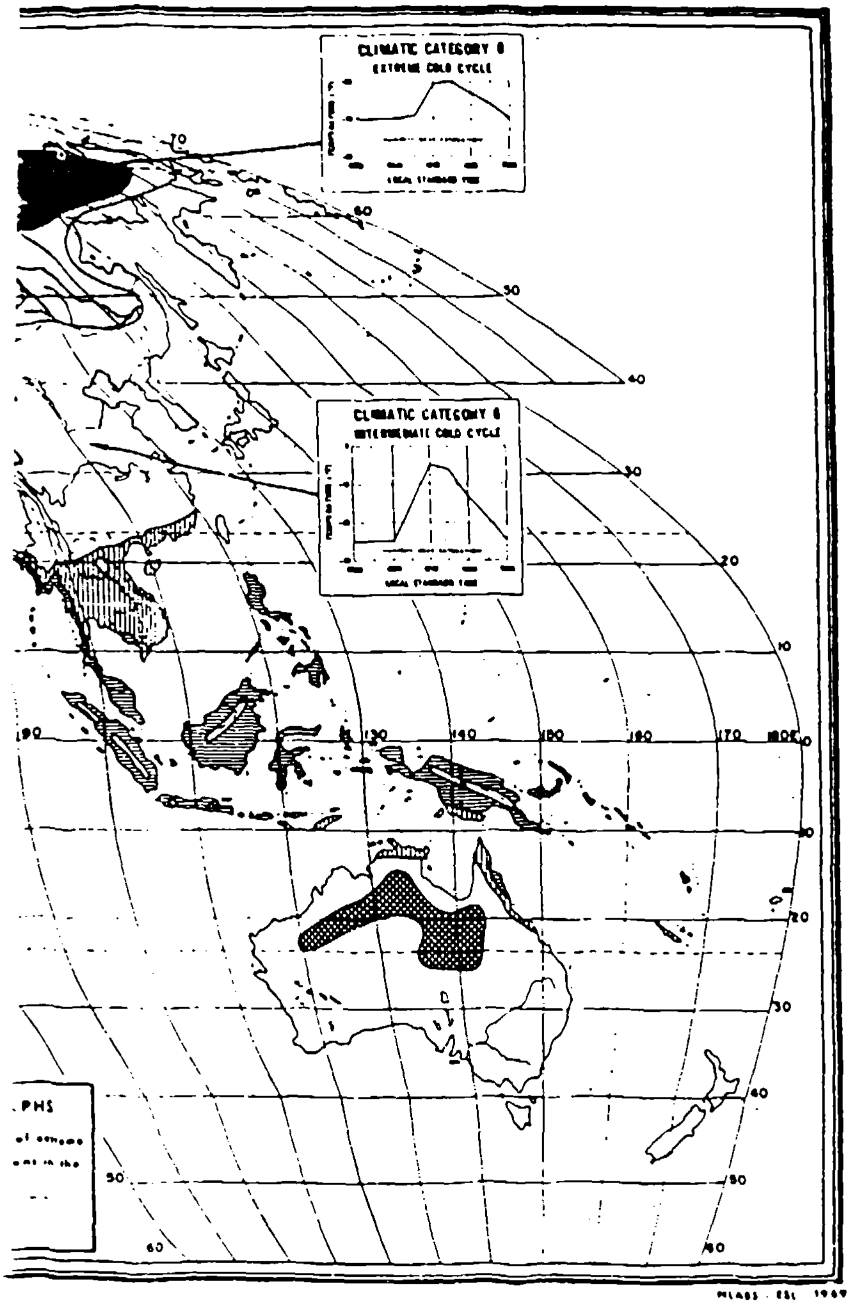

Figure 3.2.2-1. Geographic Distribution of Climate by AR 70-38 Categories.

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Table 3.2.2-1. Types and Categories of Climate

Climatic Type	Climatic Category
A. Hot - Wet	1. Wet - Warm
	2. Wet - Hot
	3. Humid - Hot Coastal Desert
B. Hot - Dry	4. Hot - Dry
C. Intermediate	5. Intermediate Hot - Dry
	6. Intermediate Cold
D. Cold	7. Cold
	8. Extreme Cold

3.2.3 Natural Environment

This section presents some general design guidelines for the protection of dormant systems from natural environmental factors. Subsequent sections of this report present more detailed design guidelines for the protection of dormant systems.

3.2.3.1 Temperature

The design of dormant systems to survive the stresses of natural and induced temperature environments is an important element of design engineering. Each item of material must be considered separately with respect to its ability to endure or to provide a useful function throughout the temperature range.

Generally, dormant systems do not experience the high temperatures experienced by operating systems. The heat dissipated by energized components in combination with the natural surrounding temperature results in higher temperatures for operating components in most cases. This lack of induced heat must be considered for dormant systems. Although high temperature requirements of dormant systems are less than those for operating systems, the same operating system heat protection devices should still be applied to dormant systems to protect the system when operation is required.

The lack of heat generation in dormant systems presents another dilemma. The generation of heat in operating systems reduces the amount of moisture present in the system. The lack of heat generation in dormant systems requires components and materials used in these systems to be adequately protected from moisture. Electronic components used in dormant systems should be hermetically sealed and corrodable materials should be coated and preserved (see section 3.2.3.2).

Table 3.2.2-2. Summary of Temperature, Solar Radiation, and Relative Humidity Diurnal Extremes. (Ref. 12.)

Climatic Category	Ambient Air Temperature °F	Solar Radiation BTU/ft^2/hr	Ambient Relative Humidity %	Induced Air Temperature °F	Induced Relative Humidity %
1. Wet-Warm	Nearly constant 75	Negligible	95 to 100	Nearly constant 80	95 to 100
2. Wet-Hot	78 to 95	0 to 360	74 to 100	90 to 160	10 to 85
3. Humid-Hot Coastal Desert	85 to 100	0 to 360	63 to 90	90 to 160	10 to 85
4. Hot-Dry	90 to 125	0 to 360	5 to 20	90 to 160	2 to 50
5. Intermediate Hot-Dry	70 to 110	0 to 360	20 to 85	70 to 145	5 to 50
6. Intermediate Cold	-5 to -25	Negligible	Tending toward saturation	-10 to -30	Tending toward saturation
7. Cold	-35 to -50	Negligible	Tending toward saturation	-35 to -50	Tending toward saturation
8. Extreme Cold	-60 to -70	Negligible	Tending toward saturation	-60 to -70	Tending toward saturation

Table 3.2.2-1 shows the climatic categories that have been selected to provide environmental guidance for the preparation of documents covering the design, development, testing and procurement of material. The conditions that establish each of the eight climatic categories are summarized in Table 3.2.3.1-1 where the temperature, solar radiation and relative humidity ranges quoted represent diurnal variations as specified in AR 70-38. Table 3.2.3.1-2 shows the diurnal temperature variation time sequence suggested for use in designing testing cycles for operational and storage conditions. (Ref. 13.)

The neutralization of temperature stresses on material is a basic design consideration. Since combination of temperature and humidity is a major source of material degradation, protective measures should be emphasized in the design of equipment and packaging for systems likely to be exposed to their joint occurrence at high levels for any sustained periods of time. (Ref. 13.) Packaging guidelines to help protect materials from moisture and temperature are presented in section 4.5 of this report.

The prevention and control of temperature stresses can be accomplished either (1) by adaptation to the thermal environment through the judicious selection of materials and choice of design configuration, or (2) by control of the immediate environment by modification of heat or cold levels through the use of temperature regulating devices. The first method is passive, and the second active. In practice the two approaches are frequently combined. (Ref. 13.)

In addition to the proper selection of materials and components, passive prevention and control methods include the following: (Ref. 13.)

1. use insulation materials and techniques

2. apply heat transfer principles (heat sinks and conduction paths)

Active methods for controlling heat or cold levels consist of devices that change the temperature levels. This is done either by the forced dissipation of excess heat or by warming, and is accomplished by the use of heat pumps, refrigeration units, fans, blowers, and heaters.

Through various qualification programs, a large variety of parts are available that are qualified for various temperature stress levels. Section 4.1 of this report and applicable component Military specifications will assist the design engineer in selecting the components for the required stress levels.

Table 3.2.3.1-1. Temperature, Solar Radiation, and Relative Humidity Diurnal Cycles for Consideration in the Development of Military Materiel. (Ref. 13.)

Climatic Conditions

Climatic Type	Climatic Category	Storage and Transit	
		Temperature °F	Relative Humidity, %
A. Hot-Dry	1. Hot-Dry	90 to 160	2 to 50
B. Hot-Wet	2. Wet-Warm	Nearly Constant 80	95 to 100
	3. Wet-Hot	90 to 160	10 to 85
	4. Humid-Hot Coastal Desert	90 to 160	10 to 85
C. Intermediate	5. Intermediate Hot-Dry	70 to 145	5 to 50
	6. Intermediate Cold	-30 to -10	High
D. Cold	7. Cold	-50 to -35	High
	8. Extreme Cold	-70 to -60	High

Table 3.2.3.1-2. Diurnal Temperature Variation Time Sequence (Ref. 13.)

Climatic Category		Hours 0300	0600	0900	1200	1500	1800	2100	2400	Temp. °F Max	Min
Hot-Dry	Storage	94	91	117	150	160	142	105	98	160	90
Intermediate Hot-Dry	Storage	71	73	117	135	145	135	100	75	145	70
Intermediate Cold	Storage	-30	-30	-28	-19	-13	-20	-26	-29	-10	-30
Cold	Storage	-50	-50	-45	-35	-35	-39	-45	-49	-35	-50
Severe Cold (North America)	Storage	-60	-60	-59	-51	-50	-53	-56	-60	-50	-60
Extreme Cold	Storage	-70	-70	-69	-61	-60	-63	-66	-69	-60	-70
For Coldest Areas (Northern Hemisphere)	Storage within 5 deg F of -80 °F for 24-hr duration										
Warm-Wet (Nonseasonal) Forest	Storage constant at 80 °F throughout 24 hr										
Wet-Hot Category (Open)	Storage	94	91	117	150	160	142	105	98	160	90
Humid-Hot Coastal Desert	Storage	94	91	117	150	160	142	105	98	160	90

3.2.3.2 Humidity

Harmful humidity effects are basically caused by unwanted moisture penetration and accumulation. Penetration by moisture can be either in the form of water vapor (and subsequent condensation), or both. Prevention and control of humidity-induce damage rests essentially, on methods designed to prevent the intrusion and/or accumulation of moisture, and those involving the selection of materials that are impervious to, or minimize, moisture-induce degradation. Specific applications are constrained by the type of item and materials used, the nature of the effects guarded against (i.e. electrical, mechanical, or chemical), and the level of component reliability required.

Prevention and control measures applicable to various classes of material are: (Ref. 13.)

1. Mechanical items. Use of proper finishes for material, use of nonabsorbent materials for gasketing, sealing of lubricated surfaces and assemblies, and use of drain holes for water run-off.

2. Electronic and electrical items. Use of nonporous insulating materials, impregnation of cut edges on plastic with moisture-resistant varnish or resin, sealing of components with moving parts, perforation of sleeving over cabled wire to avoid the accumulation of condensed water, encapsulation or sealing, and use of only pure resin as a flux.

3. Electromagnetic items. Impregnation of windings with moisture proof varnish, encapsulation, or hermetic sealing, avoidance of the use of commutators, provision of long creepage distances, and use of alumina insulators.

4. Thermally active items. Use of nonhygroscopic materials, hermetic sealing where possible.

5. Finishes. Avoidance of hygroscopic or porous materials; impregnation with wax, varnish or resin on all capillary edges.

True hermetic sealing will eliminate failures due to humidity, salt spray, fungus, and rain. True hermetic sealing is a process that includes vacuum drying by evacuation to the micron range, outgassing, quantitative leak testing, flushing with dry nitrogen, and backfilling with an inert gas. (Ref. 13.) More comprehensive packaging guidelines to reduce moisture related failures are presented in section 4.5 of this report.

The proper selection of materials and components is among the most important means for minimizing humidity-induced deterioration and failure. The part selection guidelines presented in section 4.1 of this report and the applicable Military specifications will assist the designer in selecting components for humid environments.

3.2.3.3 Atmospheric Pressure

Maximum and minimum pressure criteria that military equipment should be designed to meet at sea level and at other altitudes are given in MIL-STD-210 (Ref. 8.) and AR 70-38 (Ref. 9.). AMCP-706-116 presents extreme values of high and low atmospheric pressure as a function of altitude, latitude and probability of being exceeded 10 percent, 5 percent, and 1 percent of the time, respectively. (Ref. 13.)

Various methods are used to prevent or minimize the adverse effects of pressure. These practices include the selection of materials, proper design and utilization of sealing and pressurization techniques. The following briefly describes these methods:

1. The proper selection of materials within cost and design limitations is an important means of preventing undesirable pressure effects in dormant systems. Materials differ widely in their ability to withstand pressure-induced stresses of the type applied to containers and seals by pressure differentials resulting from rapid changes in pressure. When seeping gases or liquids are a potential problem, the permeability of materials in contact with them should be carefully evaluated. Lubricants and fuels differ in their susceptibility to evaporation and some fluids are less subject to diffusion and seepage than others. Materials for use as brushes in motors and generators vary in their resistance to failure under low-pressure conditions. The destructive effects of corona and arcing can be minimized by the proper choice of insulating materials.

2. Many adverse pressure effects can be minimized or prevented by modification of design configuration to compensate for potential problems. This is particularly true of electrical and electronic equipment where voltage breakdown at low pressures is a constant potential hazard. The shape and spacing of contacts on such equipment can affect breakdown resistance at differing voltages and altitudes.

3. Pressure levels can be maintained by sealing enclosures or containers at sea level or by blowing or pumping air into them to obtain the desired pressure. Hermetic sealing of items that have moving electrical contacts is a means of preventing explosions touched of by sparks from corona or arc-over.

Pressurization of dormant equipment can cause as well as solve problems. Equipment that is pressurized tends to be larger, heavier, and more difficult to maintain, transport and handle. Explosive decompression, sudden loss of pressure can be a major hazard. It can result from mechanical failure of the pressurizing apparatus and or seals, or from combat damage. Safeguards include the provision of a secondary pressurization system and use of pressure walls.

3.2.3.4 Solar Radiation

Ultraviolet radiation is the most destructive solar radiation. Visible radiation can also be destructive, but to a lesser extent. Infrared radiation is normally less harmful.

The ultraviolet content of sunshine causes photochemical degradation of most organic materials. Because of the deleterious effect on the relatively weak bonds of their molecular structure, the elasticity and plasticity of certain rubber compounds and plastic materials are likely to be adversely affected. The degradation is also manifested by the fading of fabric colors, and checking of paints, natural rubber, and plastics. These minute checkered patterns are exaggerated by the presence of ozone.

Optical glass exposed to ultraviolet radiation becomes increasingly opaque with radiant intensity and time. By contrast, ultraviolet radiation has little effect on the stronger chemical bonds of metals, ceramics, and inorganic compounds. The effect of ultraviolet radiation on structural metal is negligible. (Ref. 13.)

For dormant systems that are exposed to solar radiation the designer should select materials that are more resistant to degradation, and provisions should be made for replacements where degradable materials are required.

3.2.3.5 Rain

Rain - when falling, upon impact, and as deposited water - has a variety of effects on material, most of which are well known because of the pervasiveness of rain in the environment. In Table 3.2.3.5-1 some of these effects are categorized with respect to the life cycle of rain. Thus, many potential effects are not experienced except when the protective measures are compromised by error or operation expediency. (Ref. 13.)

Both AR 70-38 and MIL-STD-210 provide extreme values that general purpose equipment can be expected to encounter. Table 3.2.3.5-2 shows the rain extremes provided in AR 70-38 as a basis for design requirements.

Table 3.2.3.5-1. Effects of Rain. (Ref. 13.)

<u>On Impact</u>:

1. Erodes Surfaces
2. Imposes Large Forces on Structures

<u>After Deposition</u>:

1. Degrades Strength of Some Materials
2. Promotes Corrosion of Metals
3. Deteriorates Surface Coatings
4. Destroys or Deteriorates Many Exposed Items of Materiel -- Rations, Clothing, Repair Parts, etc.
5. Can Render Electrical or Electronic Apparatus Inoperative or Dangerous if Rain Penetrates

Table 3.2.3.5-2. Extreme Rain Conditions for General Purpose Military Equipment Design. (Ref. 9.)

Applicable to wet-warm, wet-hot, humid-hot, hot-dry, intermediate hot-dry.

Drop Size throughout: 0.6-4.0 mm, median of 2.5 mm
Windspeed throughout: 40 mph (35 kt)

Duration, hr:min	Amount, in.
0:01	0.45
0:05	1.00
0:10	1.50
1:00	4-5.5**
12:00*	9.50

* 12 hr. for wet-warm, wet-hot, intermediate hot-dry; 4 hr. for humid-hot, hot-dry.

** 4 in./hr. for humid-hot, hot-dry; 5.5 in./hr. for wet-warm, wet-hot, intermediate hot-dry.

Measures for the protection of dormant systems against the effects of moisture are discussed in section 3.2.3.2 of this text, and packaging guidelines to mitigate the effects of moisture are discussed in section 4.5. These measures are equally applicable to rain. The principal prevention and control measures discussed in these sections are as follows:

1. select materials to minimize galvanic corrosion.

2. use protective finishes (platings and/or coatings).

3. use preservatives, water repellants, and impregnants.

4. use insulation, hermetic sealing, and dehumidification.

During the design of dormant systems particular attention should be paid to the elimination of water traps, to the provision of easy access to areas of potential trouble due to moisture, and to the protection against wind-blown rain. (Ref. 13.)

3.2.3.6 Solid Precipitation

This section is concerned with those forms of ice that are derived from atmospheric moisture. Included in this section are snow, ice pellets, freezing rain, and hail. Various forms of solid precipitation are more clearly defined in Table 3.2.3.6-1. (Ref. 13.)

While the effects of the several solid precipitants can be different, there are common features based on the fact that they are all atmospherically derived frozen water. Furthermore, each of the solid precipitants can occur in combination with other environmental factors such as wind, rain, temperature, solar radiation, or humidity, in such a way as to enhance detrimental effects. (Ref. 13.)

The primary degrading factor of snow or frozen rain is the moisture that is created when either of these solid precipitants melt. Moisture protection guidelines are presented in section 3.2.3.2. Packaging guidelines to minimize the degradation induced by moisture are presented in section 4.5 of this report.

Another detrimental effect of solid precipitation is the stress loading on structures. Structures must be able to withstand the anticipated loading effect of the solid precipitation for the area. Table 3.2.3.6-2 summarizes the density of snow dependent on the type of snow cover.

Table 3.2.3.6-1. Types of Solid Precipitants and Ice Deposits. (Ref. 13.)

Term	Definition
Snow	Precipitation composed of white or translucent ice crystals chiefly in complex dendritic, tabular, stellar, or columnar forms with hexagonal symmetry. Snow is formed directly from atmospheric water vapor.
Snow pellet or graupel	Precipitation consisting of white, opaque ice particles, usually round but sometimes with traces of crystallinity, ranging from 2 to 5 mm in diameter, and of a brittle texture. Ice pellets are easily crushed but can rebound when falling on hard surfaces. They are usually formed by riming of snow crystals.
Ice pellet	Precipitation consisting of transparent or translucent pellets of ice less than 5 mm in diameter. They may be formed by freezing of raindrops or consist of snow pellets encased in a thin layer of ice.
Sleet	A term formerly applied to ice pellets and now used colloquially and in British terminology to descripe precipitation that is a mixture of snow and rain.
Hail	Precipitation in the form of rounded or irregular lumps of ice, called hailstones, which range in size from 5 to 50 mm or more in diameter and which are formed from frozen raindrops. Hailstones have a concentric layered structure usually alternating between clear and opaque ice.
Ice crystal	(diamond dust, ice needles, frost snow, snow mist) Precipitation in the form or slowly falling, very small (≈30 um) unbranched ice crystals in the form of needles, columns, or plates. Ice crystals do not reduce visibility, can be seen only in sunlight or an artificial light beam, and may precipitate from clouds or clear air.
Glaze	A dense, hard, transparent coating of ice formed on exposed objects by the freezing of supercooled rain or drizzle.
Rime	A white opaque granular deposit of ice formed by the rapid freezing of supercooled water drops as they impinge on an object. Rime is considerably less dense than glaze.
Hoarfrost	A light feathery deposit of ice consisting of interlocking ice crystals directly sublimed from water vapor onto a cold surface.

Table 3.2.3.6-2. Dependence of Density on Type of Snow Cover

Type of Snow Cover	Density, g cm^{-3}		
	Min	Max	Usual range
Dry New Snow	0.05	0.11	0.07 - 0.10
Dry Settling Snow	0.09	0.22	0.10 - 0.20
Wet Settling Snow	0.10	0.24	0.15 - 0.20
Dry Settled Snow	0.20	0.43	0.25 - 0.35
Loose, Granular Snow	0.11	0.30	0.18 - 0.28
Dry Old Snow	0.20	0.53	0.25 - 0.45
Wet Old Snow	0.28	0.52	0.35 - 0.45

3.2.3.7 Wind

Atmospheric winds transport vast quantities of heat and moisture, which ultimately affect the weather conditions distant from the air mass source regions. Strong winds accompanying hurricanes, severe thunderstorms, and other intense weather systems often damage structures, and carry materials and objects over long distances. Sand and dust transported by the wind penetrate into and damage equipment. Evaporation rates normally increase as the ventilation (wind speed) increases, resulting in loss of exposed liquids and increased wind chill. (Ref. 13.)

In designing dormant equipment, the design engineer should use hermetically sealed components and conformally coated printed circuit boards to protect material from moisture, sand and dust, and other contaminants. These design considerations will adequately protect dormant equipment from the adverse effects of contaminants transported by mild winds. The design engineer must adequately protect dormant equipment and structures from extreme winds. The design engineer should recognize that the need for protection of dormant equipment depends on the force of the extreme winds and the probability of extreme winds occurring.

When designing to withstand wind damage for a certain period of time, it is necessary to use a relation such as: (Ref. 13.)

$$Pn = 1 - [F(u)]^n$$

where

n = time interval, years

u = extreme windspeed, miles per hour

$F(u)$ = probability that windspeed u will not be exceeded in 1 year, dimensionless

$[F(u)]^n$ = probability that windspeed u will not be exceeded in n years, dimensionless

Pn = probability of at least one wind occurring with a speed u in n years, dimensionless.

Since Pn and n are chosen by the designer, it is preferable to solve for F(u), obtaining:

$$F(u) = (1 - Pn)^{1/n}$$

For long recurrence intervals, the estimates of extreme wind probability are statistically rather than observationally derived. Hence, confidence intervals to reflect the variability of observation from estimates should be placed upon the probability estimates. Table 3.2.3.7-1 gives the extreme wind probabilities.

Table 3.2.3.7-1. Ninety-Percent Confidence Limits on Extreme Wind Probability. (Ref. 14.)

PROBABILITY	LOWER LIMIT	UPPER LIMIT
0.50	0.407	0.593
0.90	0.827	0.945
0.96	0.827	0.982
0.98	0.908	0.992
0.99	0.955	0.995

3.2.3.8 Salt Fog

The principal effect of salt on materials is the acceleration of metallic corrosion. Consequently, corrosion prevention must be a primary concern of the designer. The protection of metal from corrosion is discussed in detail in section 4.5.

3.2.3.9 Sand and Dust

Sand and dust primarily degrade equipment by:

(1) Abrasion leading to increased wear,

(2) Friction causing both increased wear and heat, and

(3) Clogging of filters, small apertures, and delicate equipment.

Although, friction and abrasion are not concerns for dormant systems while the systems are in a nonoperational state, sand and dust buildup on potential moving components must be considered. The buildup of sand and dust on contact surfaces or moving parts will degrade the operational readiness of dormant systems. Hermetic sealing of electrical components, conformal coatings on electrical boards and proper system packaging will eliminate sand and dust buildup in dormant systems. Equipment having moving parts require special care when designing for sand and dust protection. Sand and dust will abrade optical surfaces, either by impact when carried by air, or by physical abrasion when the surfaces are improperly wiped during cleaning.

Dust accumulations have an affinity for moisture and, when combined, may lead to corrosion or the growth of fungus.

In the relatively dry regions, such as deserts, fine particles of dust and sand are readily agitated into suspension in the air where they may persist for many hours, sometimes reaching heights of several thousand feet. Thus, even though there is virtually no wind present, the speeds of vehicles or vehicle-transported equipment through these dust clouds can cause surface abrasion by impact, in addition to the other adverse effects of the sand or dust.

Although dust commonly is considered to be fine, dry particles of earth, it also may include minute particles of metals, combustion products, solid chemical contaminants, etc. These other forms may provide direct corrosion or fungicidal effects on equipment, since this dust may be alkaline, acidic, or microbiological.

Since dust is present in almost any environment, the question is not whether to allow dust to enter, but, rather, how much or what size dust could be tolerated. The problem becomes one of filtering any circulating air to remove dust particles above a nominal size. The nature of filters, however, is such that for a given working filter area, as the ability of the filter to stop increasingly smaller dust particles is increased, the flow of air or other fluid through the filter is decreased. Therefore, the filter surface area either must be increased, the flow of fluid through the filter decreased, or the allowable particle size increased, i.e., invariably there must be a compromise. Sand and dust protection, therefore, must be planned in conjunction with protective measures against other environmental factors. It is not practical, for example, to specify a protective coating against moisture if sand and dust will be present, unless the coating is carefully chosen to resist abrasion and erosion, or is self-healing.

3.2.3.10 Fungus

Fungi adversely affect items of equipment utilizing cotton, linen, natural rubber, hair, cork, leather, paper, felt, wood, cement, glue, bonding materials and other organic materials that are nutrients for fungi, unless these materials are treated to resist them. Fungi will grow on all cellulosic material; animal and vegetable oils; waxes; plastics with linen, cotton, wood flour, or other organic filler; and thermoplastics which are highly plasticized, where the plasticizing liquids frequently are susceptible components. If nutrient is present, fungi will grow upon any metal, plastic, ceramic or asphalt, and may damage them to some extent. Fungi can cause complete degradation of most cellulosic materials. Chemically altered cottons, such as acetylated and cyanoethylated, show a high degree of resistance to deterioration caused by fungi.

Fungi adversely affect the functioning of electronic and electrical equipment because of inherent fungal properties and by aggravating the effects of moisture. Certain types of insulation and plasticizers, and fillers of molded and laminated plastics support fungal growth. The mycelium is electrically conductive, and fungal masses encourage moisture condensation and retard drying by interfering with air diffusion. Hyphal strands of surface fungi can introduce leakage paths which unbalance electronic circuits and establish couples which promote electrolytic corrosion. Absorption of moisture lowers the electrical resistance of dielectrics, films of water can cause surface leakage, and absorption within a capacitor or coil can bring about alteration in electrical constants of a circuit.

Corrosion of metal parts is encouraged through moisture retention by surface-growing fungi and by organic acids produced in their metabolic activity.

Where consideration must be given to fungi as an environmental factor, selection of nonfungus supporting materials will suffice in most cases. Table 3.2.3.10-1 lists materials considered fungus-inert. Refer also to MIL-STD-454 for more fungus-inert materials.

If critical circuits requiring high fungal resistance are involved it may be necessary to fungus-proof with appropriate compounds. Table 3.2.3.10-2 lists commonly used fungicides. The following is a list of design guidelines to protect dormant systems against fungus:

1. Use fungus-resistant materials that also meet strength, weight, environmental, and mechanical requirements.

2. Apply fungicidal treatments or coat the material with a seal that is impervious to moisture, but fungicidal treatments are only effective for limited periods and must be reapplied.

3. Use hermetic sealing, wherever possible. If hermetic sealing is not possible, use gaskets and other sealing devices to keep out moisture. Make sure the sealing devices do not contribute to fungal activity. Detect and eliminate any moisture entry points.

4. Use materials with low moisture absorption qualities.

5. When treated materials are used, make sure they do not contribute to corrosion or alter electrical or physical properties.

3.2.3.11 Space Environment

Polymers are the materials most likely to be affected by exposure to the environment of outer space. Most of the organic materials used in spacecraft are long-chain polymeric compounds which degrade in a vacuum not by evaporation or sublimation but by breakdown of the compounds into smaller, more volatile fragments. This decomposition takes place not at the surface but throughout the volume of the piece. Polymers are commonly more stable at elevated temperatures in the absence of oxygen. (Ref. 16.)

Coatings may be put over organic materials to reduce their net rate of breakdown in vacuum. The coatings prevent degradation products from leaving the underlying material and permits them to recombine to some

Table 3.2.3.10-1. Fungus-Inert Materials

Acrylics	Polycarbonate
Acrylonitrilestyrene	Polyester-glass fiber laminates
Acrylonitrile-vinyl chloride copolymer	Polyethylene, high density (above 0.940)
Asbestos	Polyethylene terephthalate
Ceramics	Polyimide
Chlorinated polyether	Polymonochlorotrifluorethylene
Fluorinated ethylenepropylene	Polypropylene
Glass	Polystyrene
Metals	Polysulfone
Mica	Polytetrafluoroethylene (TFE)
Plastic laminates	Polyvinylidene chloride
Silicone glass fiber	Silicone resin
Phenolic nylon fiber	Siloxane-polyolefin polymer
Diallyl phthalate	Siloxane-polystyrene
Polyacrylonitrile	
Polyamide	

Table 3.2.3.10-2. Commonly Used Fungicides.

Government-Approved Fungicides	Other Fungicides
Textiles, hemp, and jute	Textiles
Copper 8-quinolinolate	Copper naphthenate, 2, 2' methylenebis (4-chlorophenol)
Plastics and electronic equipment	Paper
Paraphenyl phenol-formaldehyde with salicylanilide	Chlorinated pheols (pentachlorophenol)
Leather products	Rubber
Paranitrophenol	Nitrophenol, zinc salicylate [1%0, zinc bezonate (1%)]
Textiles	Paints, varnishes, enamels, and lacquers
Dihydroxyl dichlorodiphenylmethane	Clorinated, phenols, salicylanilide

Wood Preservatives

Coal-tar creosote compounds, carbolineums, wood-tar creosotes, pentachlorophenol, copper napthenates, chromated zinc cjloride, chemonite zinc naphthenates, "Wolman" salt tanolith, zinc chloride, zinc metacresenite, and copper chromated zinc chloride.

extent. If organic materials are used in partial enclosures containing temperature gradients and exposed to vacuum, there is a possibility that they will decompose to volatile products in the warmer areas, and that the volatiles will redeposit on the cooler surfaces. If the cooler surfaces must conduct electricity or heat, this may lead to malfunction. In particular, plasticizers can redeposit on exposed relay contacts and prevent them from closing properly. (Ref. 16.)

Most polymers will be stable in the vacuum of space at temperatures as high as they can withstand in air. Important exceptions are some nylons, polysulfides, cellulosics, acrylics, polyesters, epoxies, and urethanes. Vacuum stability is sensitive to formulation and curing procedure; addition agents such as plasticizers, mold lubricants, and polymerization catalysts are generally detrimental. Exposure to vacuum will not cause loss of engineering properties unless appreciable loss in weight occurs. Table 3.2.3.11-1 gives an estimated order of merit for the behavior of polymers in vacuum, together with temperatures where the estimated weight loss is 10% per year. (Ref. 16.)

The particles of the Van Allen radiation belts will damage engineering properties of all exposed polymer surfaces; solar flare emissions will probably affect exposed surfaces of the materials more sensitive to radiation damage. Radiation protection guidelines are presented in section 3.2.5.2. (Ref. 16.)

3.2.4 Induced Environmental Factors

The induced environmental factors, consist of the following elements:

1. Mechanical factors - shock, vibration, and acceleration
2. Radiation - nuclear, thermal, and electromagnetic
3. Atmospheric pollutants

The characteristics describing mechanical factors may be presented in any of several different ways. Basically, vibration is defined in terms of repeated displacement versus time; shock is defined in the same units but is not repetitive. Acceleration is usually presented in gravitational units, and acoustical vibration is described in decibels and frequency.

Shock connotes impact, collision, or blow, usually caused by physical contact. It denotes a rapid change of load, or a rapid change of acceleration with a resultant change of load. Shock occurs when a structure is subjected to a suddenly applied force, resulting in transient vibration of the structure at its natural frequencies. The

Table 3.2.3.11-1. Decomposition of Polymers in High Vacuum. (Ref. 16)

Polymer	Temperature for 10% weight loss per year in vacuum °C	°F
Nylon	30 - 210	80 - 410
Sulfide	40	100
Cellulose nitrate	40	100
Cellulose, oxidized	40	100
Methyl acrylate	40 - 150	100 - 300
Ester	40 - 240	100 - 460
Epoxy	40 - 240	100 - 460
Urethane	70 - 150	150 - 300
Vinyl butyral	80	180
Vinyl chloride	90	190
Linseed oil	90	200
Neoprene (chloroprene)	90	200
Alkyd	90 - 150	200 - 300
Methyl methacrylate	100 - 200	220 - 390
Acrylonitrile	120	240
Isobutylene-Isoprene (butyl rubber)	120	250
Styrene-buladiene	130	270
Styrene	130 - 220	270 - 420
Phenlic	130 - 270	270 - 510
Butadiene-acrylonitrile (nitrite rubber)	150 - 230	300 - 450
Vinyl alcohol	150	310
Vinyl acetate	160	320
Cellulose acetate butyrate	170	340
Cellulose	180	350
Carbonate	180	350
Methyl styreno	180 - 220	350 - 420
Cellulose acetate	190	370
Propylene	190 - 240	370 - 470
Rubber, natural	190	380
Melamine	190	380
Silicone elastomer	200	400
Ethylene tereplithalaie (nylon, dacron)	200	400
Isobutylene	200	400
Vinyl toluene	200	400
Styrene, cross-linked	230 - 250	440 - 490
Butadiene-styrene (GR-2 = SBR)	240	460
Vinyl fluoride	240	460
Etylene, low density	240 - 280	460 - 540

Table 3.2.3.11-1. Decomposition of Polymers in High Vacuum. (Ref. 16) (Continued)

Polymer	Temperature for 10% weight loss per year in vacuum	
	°C	°F
Butadiene	250	490
Vinylidene flouride-hexaflouropropene	250	490
Chlorotrifluoroethylene	250	490
Chlorotrifluoroethylene-vinylidene flouride	260	500
Vinylidene flouride	270	510
Benzyl	280	540
Xylylene	280	540
Ethylene, high density	290	560
Trivinyl benzene	290	560
Tetrafluoroethylene	380	710
Methyl phenyl silicone resin	380	710

magnitude of the vibration may become great enough to cause fracturing of brittle material or yielding of ductile material.

Vibration is an oscillation in which the quantity is a parameter that defines the motion of a mechanical system. Vibration has also been described as the variation, usually with time, or the magnitude of a quantity to a specified reference, when the magnitude is alternately greater and smaller than the reference. Vibration may be periodic, consisting of motions at one or more frequencies with the motion at each frequency being harmonic, or it may be random, in which case the amplitudes and various frequencies vary randomly with respect to time. An additional type of vibration, termed white-noise vibration, has no defined frequencies of motion. The excitation forces that cause vibration may be mechanical in nature, such as caused by a reciprocating motion or they may be acoustic in nature, such as caused by rocket engine noise.

Acceleration is the change of velocity, or the rate of change of either speed or direction, or both. Whether displacement, velocity, or acceleration is used in defining shock, the implication of a relatively sudden change is always present. Acceleration by itself does not constitute shock. For example, a structure subjected to steady-state acceleration is not considered to be undergoing shock.

Excessive noise produces adverse effects on equipment and on structures. It also induces and augments vibration and the adverse effects of vibration. Malfunction and fatigue failure of electronic equipment are possible at noise levels above 130 decibels (dB).

Nuclear explosion factors are the phenomenon associated with the explosion or detonation of nuclear devices. The nuclear explosion factors of interest in this section are: radiation effects and electromagnetic pulse effects. Radiation effects are either pure energy such as X or gamma rays, or particulate energy such as alpha or beta particles, or neutrons. Nuclear radiation intensity is expressed as unit energy per unit time, such as erg/sec or ev/sec. Radiation received is usually measured in rads where a rad is a unit of absorbed dose equal to 100 ergs/g of absorbing material. Identification of the type of radiation, intensity, duration (half-life) and dose rate are all of primary importance.

Nuclear explosions produce electromagnetic pulse (EMP) either through assymetry in the electric charge distribution in the region of the detonation or through the expansion of plasma in the earth's magnetic field. Voltages generated by this phenomenon are coupled into the susceptible receiver.

Atmospheric pollutants are considered to be principally any airborne man-made solid, gas, or liquid contaminants although naturally occurring contaminants such as both solid and liquid volcanic materials are encountered. Protection from atmospheric pollutants is achieved in the same manner as sand and dust protection described in section 3.2.3.9.

3.2.5 Induced Environment

This section presents general design guidelines for the protection of dormant systems from induced environmental factors. Subsequent sections of this report present more detailed design guidelines for the protection of dormant systems.

3.2.5.1 Mechanical Factors

Mechanical factors that may be encountered by dormant systems include: shock, vibration, and acceleration. The following subsections present basic design guidelines for the protection of dormant systems from mechanical shock environments. Subsequent sections of this report present more detailed guidelines for the protection of dormant systems from mechanical environmental factors encountered during transportation and handling and storage.

3.2.5.1.1 Vibration

The most severe vibration encountered by most dormant systems is the vibration encountered during transportation and handling. The transport vehicle as well as the handling and service systems is often characterized by severe vibratory stresses. Thus, data on vibrations encountered in the transportation of the dormant system is essential. The following is a general summary of the most common forcing frequencies that will be encountered by different transportation carriers:

(a) Railroad : 2 to 7 Hz

(b) Truck: 5 to 500 Hz

(c) Aircraft: 20 to 60 Hz

(d) Ships: 11 to 100 Hz

The mode of transportation and the applicable frequencies tabulated provide the required data relating to imposed vibrations. The designer must assure that the dormant system is capable of withstanding the vibrations imposed by the above transportation vehicles. Packaging, or cushioning guidelines to protect the system from vibration encountered during transportation can be found in sections 4.5 and 4.6 of this report.

Vibration may affect material in many ways. Generally, these may be classified into one or more of the following categories: (Ref. 14.)

1. Malfunction of sensitive electrical, electronic, and mechanical devices
2. Mechanical and/or structural damage to structures both stationary and mobile
3. Frothing or sloshing of fluids in containers

Table 3.2.5.1.1-1 summarizes possible vibration induced damages to electrical and electronic components.

The process of reducing the effects of the vibration environment on material is known as vibration control. Essentially vibration control consists of varying the structural properties of systems, such as inertia, stiffness, and damping properties, in order to attenuate the amount of vibration transmitted to material or to reduce the effects of the vibration transmitted to the material.

3.2.5.1.2 Shock

Dormant systems must be capable of surviving, without damage, the shock environment induced by transportation, handling, storage, and maintenance systems as well as that experienced in the operational environment of the equipment. Shock is considered a special case of vibration wherein the excitation is a relatively short-term disturbance that has not reached or has ceased to be steady state. The excitation is nonperiodic, usually in the form of a pulse, step, or transient vibration. Shock excitation is generally described by a time history of the rapid variation in the force applied to the system, or by displacement, velocity, or acceleration imposed upon the system. Acceleration is the most frequently measured shock parameter. (Ref. 14.)

One of the major problems in transporting material between any two locations is the shock environment to which it is exposed. The following is a summary of the most severe shocks encountered in the four basic transportation modes: (Ref. 14.)

1. aircraft - greater than 12 G with durations less than 0.1 sec during landing and takeoff

Table 3.2.5.1.1-1. Vibration-Induced Damage to Electrical and Electronic Equipment. (Ref. 14.)

Component Category	Damage Observations
Cabinet and Frame Structures	Among some 200 equipment cabinet and frame structures subjected to shock and vibration, damage included 30 permanent deformations, 17 fractures in areas of stress concentration, two fractures at no apparent stress concentrations, 23 fractures in or near welds, and 26 miscellaneous undefined failures.
Chassis	Nearly 300 chassis subjected to shock and vibration experienced 18 permanent deformations, eight fractures in or near welds, nine fractures at no apparent stress concentrations, 46 fractures at points of stress concentration, and 12 miscellaneous failures.
Cathode-Ray Tubes	Cathode-ray (CR) tubes are susceptible to vibration damage if they are improperly mounted and supported. CR tubes with screens larger than 5 in. are particularly susceptible. Of 31 cathode-ray tubes subjected to shock and vibration, the deflection plates of one tube became deformed, another had a filament failure, five suffered envelope fractures, and one had a glass-socket seal break.
Meters and indicators	Although the moving coil type of meter comprises the majority of units in this category, other indicators include Bourdon tubes and drive-type synchros. Of the latter group, most of the failures were either erratic performance or zero shift difficulties. Nearly 200 units subjected to shock and vibration. Two suffered permanent deformation of the case, one had elements loosened, 12 gave erratic readings, one had the glass face fractured, two developed internal open circuits, two had loose or damaged pivots, three had deformed pointers, and 10 others failed from miscellaneous causes.
Wiring	Wiring failure from shock and vibration is a serious problem. A defect not only results in malfunctioning of the equipment but presents a difficult troubleshooting job in locating the wire break.
Transformers	In electronic equipments transformers are probably the heaviest and densest components found on an electronic chassis. Because of the weight and size of transformers, shock and vibration are more likely to produce mechanical rather than electrical failures. While not all mechanical failures immediately prevent the transformer from functioning properly, they eventually result in destruction of the transformer and damage to surrounding components.

2. rail - 30 to 50 G during humping operation

3. sea - less than 2 G

4. highway - maximum of 10 G, but usually in the range of 1 to 2 G

Handling shocks are usually generated by flat drops on a hard surface, such as dropping a package on a concrete surface from the tailgate of a truck during unloading operations. Handling shocks are usually described by the impact velocity or the drop height and angular orientation at impact. The shocks are generally less severe than a 36 inch drop on concrete, which corresponds to a velocity change of approximately 165 inches per second. (Ref. 14.)

Storage shock environment includes those shocks experienced by material while in warehouses or storage areas for any extended period. Shocks typically occur from being moved by forklift and from being struck by other packages during stacking operations. The acceleration values usually don't exceed 4 G. (Ref. 14.)

The resistance of an item to shock constitutes its ability to withstand impact without damage. The fragility rating of an item is a quantitative description of this ability. Fragility rating is expressed as an acceleration in G units. Specifically it is a measure of the maximum shock levels that an item can withstand yet still function properly. Therefore, if the estimated shipping and handling shock environment is greater than the fragility rating of the item some form of shock mitigation system must be employed. Fundamentals of package design, barrier, cushioning, and container design are discussed in section 4.5 of this report.

3.2.5.1.3 Acceleration

Dormant systems that are subjected to relatively long periods of acceleration will suffer the same types of damage which result from exposure to shock and vibration environments but with much less frequency and severity. Acceleration causes a mechanical force to act on an item so that its ability to survive acceleration is a measure of its structural integrity. Equipment designed to operate in shock and vibration environments will in most cases survive the operational acceleration environment with no ill effects. However, certain devices such as panel meters, electromechanical time-delay relays and accelerometers may be affected more seriously by acceleration than by shock or vibration. (Ref. 14.)

When a transport vehicle (rail or highway) accelerates from 0 to 60 miles per hour (mph) in 30 seconds, the acceleration is approximately 2.9 ft/s^2, to do so in 10 seconds the acceleration is 8.8 ft/sec^2. In terms of G, these accelerations are 0.09 and 0.27 respectively. Transport aircraft do not exceed these G levels in normal operation. To reach a takeoff speed of 120 miles per hour in 30 seconds, the acceleration is approximately 0.18 G; in normal flight, the maximum acceleration is from 0.04 to 0.06 G; and in maneuvers such as a turn with a 30 degree bank angle, the maximum acceleration is 0.25 G. Thus, normal accelerations on land vehicles and aircraft will be below 0.3 G. (Ref. 14.)

Table 3.2.5.1.3-1 summarizes some of the effects of acceleration.

The primary means of protecting dormant systems from the acceleration environment is through proper packaging. In order to effectively package an item for shipment or storage, the fragility rating of the item must be known as well as the environmental levels that are likely to be encountered. Packaging guidelines are presented in section 4.5 of this report.

3.2.5.2 Nuclear Radiation

Although a natural background level of nuclear radiation exists, the only terrestrial nuclear radiation that is of interest is that associated with man made sources such as reactors, isotope power sources, and nuclear weapons. The most important of these sources is nuclear weapons, the effects of which can produce both transient and permanent damaging effects in a variety of materials. In space various levels of radiation also exist.

X rays, gamma rays, and neutrons are the types of nuclear radiation of most concern. As opposed to charged nuclear particles, which also emanate from nuclear reactions, those forms of radiation listed have long ranges in the atmosphere; thus, they can irradiate and damage a variety of materials.

Among the nuclear effects that have been of most concern are those called "Transient Radiation Effects on Electronics". These are due to the transient radiation pulse from a tactical nuclear burst and are often referred to as TREE. These transient effects are due primarily to the ionization and total dose effects of gamma rays and X rays, as well as induced permanent lattice defects due to neutron fluence. The separation of upset effects and permanent effects is made on the basis of the processing of erroneous data or damage to the device structure. For example, a large current pulse may be produced by ionizing radiation, and this current pulse may result in permanent damage to a device by overstress. The permanent damage results from overstress due

Table 3.2.5.1.3-1. Effect of Acceleration on Military Equipment. (Ref. 14.)

Item	Effect
Mechanical: moving parts, structures, fasteners	Pins may bend or shear; pins and reeds deflect; shock mounts may break away from mounting base; mating surfaces and finishes may be scoured.
Electronic and electrical	Filament windings may break; items may break away if mounted only by their leads; normally closed pressure contacts may open; normally open pressure contacts may close; closely spaced parts may short.
Electromagnetic	Rotating or sliding devices may be displaced; hinged part may temporarily engage or disengage; windings and cores may be displaced.
Thermally active	Heater wires may break; bimetallic strips can bend; calibration may change.
Finishes	Cracks and blisters may occur.
Materials	Under load, materials may bend, shear, or splinter; glue lines can separate; welds can break.

to excess current rather than to direct radiation-induced material property change. Generally, total dose effects from X rays and gamma rays have no effect on dormant electronic equipment. The designer must still consider these environments when designing dormant systems in order to insure operational readiness in total dose environments.

Table 3.2.5.2-1 presents a basic summary of nuclear radiation environments and basic protective measures.

It is impossible to completely protect a system from nuclear radiation as can be accomplished for some other environmental factors. The variety of effects produced by nuclear radiation for different materials and components makes protective design difficult. The most common procedure employed is to define a radiation hardness level in a given material item and to design and test the item to that level.

3.2.5.3 Atmospheric Pollution

Air pollution may be defined as the presence of foreign matter suspended in the atmosphere in the form of solid particles, liquid droplets, gases, or in various combinations of these forms in sufficient quantities to produce undesirable changes in physical, chemical, or biological characteristics of the air. Table 3.2.5.3-1 summarizes basic material categories, how they are affected by atmospheric pollutants, and the specific pollutants involved. (Ref. 14.)

The severity with which atmospheric pollutants attack materials will in general vary with the locale and the season. The rate of attack is influenced by the relative humidity, the extent of the pollution, the quantity and frequency of rainfall, air movement characteristics, the frequency of occurrence and duration of fog, the proximity to the sea, the amount of solar radiation, and temperature ranges.

There would be very little, if any, atmospheric corrosion, even in the most polluted atmospheres, without moisture. Most metals have a critical relative humidity threshold below which the rate of corrosion is very slow, but when exceeded produces a rapid rise in the rate of corrosion. Rain can increase the rate of some metals while it decreases that of others. By washing the surface of a specimen, rain can remove corrosive pollutants that have collected on the surface, thus reducing the corrosion rate. In other cases, it can remove soluble corrosion products that had been protecting the material. Fogs and dews are, in general, damaging because they have no washing effect on the surface but rather form surface films of moisture which absorb pollutants from the atmosphere. (Ref. 14.)

Table 3.2.5.2-1. Summary of Nuclear Radiation Environments and Basic Protection Measures.

Radiation Source	Radiation Environment	Dormancy Storage Guidelines
Tactical	Radioactive debris, X-rays, Charged Particles, Neutrons	Seal circuits to avoid contamination radioactive debris. Shield Ground Base Systems Use devices with narrow junction size or minimum base width. Fast switching speeds when possible Design for reduced gain reduction in efficiency and an increase in: leakage current, rev. breakdown voltage, and forward voltage.
Space	Electrons, Protons, X-rays, Gamma rays, Heavy Ions	Shielding may be used against light, charged particles; however; surface charging and discharging to internal circuitry is a serious problem and must be considered during design. Gamma rays and X-rays cause total dose damage in passive and optical materials (i.e., teflon). Use existing data to determine severity for specific application. Heavy ions affect the atomic structure of the device. Similar to neutrons and are usually charged causing electrical disturbancies in charge sensitive devices. However, this rate of incidence is low and may have no effect.

Table 3.2.5.3-1. Air Pollution Damage to Various Materials. (Ref. 14.)

Materials	Typical Manifestation	Measurement	Principal Pollutants	Other environmental Factors
Metals	Spoilage of surface, loss of metal, tarnishing	Weight gain of corrosion products, weight loss after removal of corrosion products, reduced physical strength, changed reflectivity or conductivity	SO_2, acid gases	Moisture, temperature
Building materials	Discoloration, leaching	Not usually measured quantitatively	SO_2, acid gases, sticky particulates	Moisture, freezing
Paint	Discoloration, softened finish	Not usually measured	SO_2, H_2S, sticky particulates	Moisture, fungus
Leather	Powdered surface, weakening	Observation, loss of tensile strength	SO_2, acid gases	Physical wear
Paper	Embrittlement	Decreased folding resistance	SO_2, acid gases	Sunlight
Textiles	Reduced tensile strength, spotting	Reduced tensile strength, altered fluidity	SO_2, acid gases	Moisture, sunlight, fungus
Dyes	Fading	Fading by reflectance measurements	NO_2, oxidants, SO_2	Sunlight, moisture
Rubber	Cracking, weakening	Loss in elasticity, increase in depth of cracks when under tension	Oxidants, O_3	Sunlight
Ceramics	Changed surface appearance	Changed reflectance measurements	Acid gases	Moisture

Temperature influences the rate of those chemical reactions that cause material deterioration. The temperature also determines the rate of drying or the length of time that a surface remains wet. During an atmospheric temperature inversion, exposed objects, especially metals, lose heat rapidly and cool to temperatures below that of the ambient air. If their surface temperature falls below the dewpoint, the surfa ɔ becomes moist and, in the presence of corrosive pollutants whose concentrations are increasing due to the temperature inversion, create a situation conducive to material damage. (Ref. 14.)

Sunlight energy is an important element in the nitrogen dioxide photolytic cycle in which damaging agents such as ozone and hydrocarbon free radicals are formed in a series of complex photochemical reactions in the atmosphere. (Ref. 14.)

Air movement tends to disperse pollutants throughout the atmosphere. Specific design steps for protection against the effects of pollutants are not common, since protection is normally obtained by methods employed for protection against other environmental factors. (Ref. 14.)

Metals exhibit varying degrees of susceptibility to atmospheric pollutants. Therefore, the proper choice of metal or alloy is important for dormant equipment components that will be exposed to polluted atmospheres. Aluminum, stainless steels, and copper generally suffer no adverse effects from atmospheric pollution. Ordinary carbon ste' require some form of protection when exposed to atmospheric co.. tions. Preservatives and coatings are discussed in section 4.5 of this report. (Ref. 14.)

Complex prec. .on electronic systems, such as computers and switching networks, ha been affected by high concentrations of particulate matter and sulfur dioxide. Dormant systems that are exposed to air pollutants should be installed in an air-tight container.

Semiconductor devices, integrated circuits, relays, switches, etc. are susceptible to air pollutants. If used in dormant systems, these devices should be hermetically sealed to preclude any future damage from air pollutants. (Ref. 14.)

Electrical contacts, such as those on relays and switches, are susceptible to particulate matter, hydrogen sulfide, and sulfur dioxide. These components should be hermetically sealed when possible to prevent damage from air pollutants. (Ref. 14.)

3.3 DORMANT STORAGE

This section describes the dormant storage environment and its effects on systems. Section 3.2 presented the primary degrading environments that may be encountered by dormant systems. Section 3.2 also presented some basic design guidelines that will assist the design engineer in designing adequate protection for dormant equipment. Subsequent sections of this report present more detailed design guidelines for protecting systems during dormant storage.

3.3.1 Storage Types, Capacities, and Limitations

Dormant storage types can be classified by the type of shelter facility: (Refs. 2, 3.)

Type 1 - outside storage

Type 2 - sheltered storage

Type 3 - dehumidified structural storage

Type 4 - dehumidified nonstructural storage

Type 1 outside storage consists of a storage area which is exposed to all extremes of local, natural environments. Outside storage can be an improved storage space or an unimproved storage space. The open improved storage space is an area that has been graded and hard surfaced, or prepared with a topping (such as steel mats) to permit effective material handling. Open unimproved storage space is an open area that has not been surfaced for storage purposes. Outside storage is suitable only for materials that are not readily damaged by weather conditions. The packaged item must also be protected from fungi, pests, dust, and pilferage. In many cases, tarpaulins must be provided to cover stored items. The open unimproved storage space has an additional limitation in its susceptibility to wet ground conditions which can limit the satisfactory operation of materials handling equipment. Material which is expected to be stored in outside storage should be packaged, and should be constantly surveyed for evidence of deterioration. Packaging guidelines to protect dormant systems are presented in section 4.5 of this report.

Type 2 sheltered storage consists of ventilated or unventilated, heated or unheated buildings, shelters or enclosures of structural characteristics that are designed to afford protection from the elements. The stored material is not protected from atmospheric changes of temperature and humidity. Periodic surveillance and maintenance are required to keep deterioration to a minimum. These types of structures include every type of covered storage space including general purpose warehouses, flammable storage warehouses, transit sheds, dry tanks, and typical storage sheds.

Type 3 dehumidified structure storage consists of a structure in which the atmosphere is maintained at a relative humidity of 40 percent or less. Controlled humidity storage in structures provides the highest degree of protection and is the most economical method of storage for items of a critical nature since little surveillance and maintenance is required. When properly sealed and conditioned, almost any type of warehouse may be dehumidified. In actual practice, however, the general warehouse is the structure most often converted for dehumidified storage. Dehumidification has proved to be the most economical and efficient method of preservation for many classes of items and is being used increasingly. Whenever possible, Type 3 storage should be used for dormant systems because it offers the best protection against natural environmental factors.

Type 4 dehumidified nonstructural storage consists of complete or partial sealing of the packaged item, with mechanical or static dehumudification controlling the relative humidity inside the package to a maximum of 40 percent. A typical dehumidifier which automatically reactivates the desiccant is specified in MIL-D-16886. This dehumidifier is classified by the type of heat used for dessicant reactivation. Controls are electrically operated. (Ref. 1.) Other dessicants and dehumidifiers are specified in MIL-D-3263A, MIL-D-43266, MIL-D-3716, AND MIL-D-3464. Type 4 storage is recommended for dormant system protection whenever Type 3 storage is not possible.

Table 3.3.1-1 presents some of the environmental conditions in storage facilities.

Table 3.3.1-1. Typical Environmental Conditions in Storage Facilities. (Ref. 13.)

Environment	Temperature °F	Relative Humidity %	Water Vapor Partial Pressure, in. Hg
Open Slab & Shed	61.1	68.9	0.378
Standard Warehouse	66.0	55.0	0.363
50% RH Warehouse	66.5	49.0	0.327
40% RH Warehouse	67.3	39.7	0.272

3.3.2 Storage of Explosive Material

The storage of explosive material is determined by the potential hazards of the material. Materials of an explosive nature must be stored in standard ammunition magazines designed for that purpose, in areas designated specifically for the storage of explosives, ammunition, or similar components. These areas are usually not wired for electricity and generally are not heated. Therefore, the packaged item must be adequately preserved to protect it from deterioration. The package should be designed to facilitate inspection required by periodic monitoring and surveillance without removal of the covering.

Earth-covered magazines offer the greatest protection to explosives and afford the greatest degree of protection from the results of an explosion. Such magazines are preferred for the storage of all explosives. Other types of magazines built in accordance with approved drawings may be used as conditions dictate. Refer to DOD 4145.27M, DOD Ammunitions and Explosives Safety Standards, for magazine siting requirements. Outdoor storage is not considered desirable. Priority for indoor storage should be given to items requiring the most protection from the weather. High explosives, solid propellants, pyrotechnics, and critical items should not be stored outside. The basic types of magazines are the igloo, and above ground magazines. (Refs. 2, 3.)

The igloo is used for the storage of ammunition and high explosives. An igloo is a type of magazine and is generally constructed of reinforce concrete or corrugated steel with an arch type roof covered with earth. Igloos may or may not be ventilated, and although unheated,, the temperature in unventilated igloos usually ranges from 40 to 45 degrees F in winter, and 60 to 70 degrees F in summer. The arched roof of the typical igloo limits the storage height of the explosives.

The above ground magazine is designed and used for the storage of ammunition and explosives and is constructed with roof, side walls, and end walls. Because of the nature of the items stored in them, above ground magazines should be built of fire-resistant materials, and should be ventillated to prevent temperature build-up. They should be widely separated to minimize the destructiveness of an explosion, should one occur.

The propulsive characteristics of explosive items such as rockets, rocket motors, assist take-off units, and missiles must be taken into consideration during all phases in order to obtain as much safety as possible under the circumstances. Rockets and like items should be stored in cool, dry magazines and never in direct rays of the sun. An environment as near "optimum" as possible for the particular item will afford the safest storage condition, and consideration should be given to this aspect. However, the design upper and lower temperature limits specified for the item should not be exceeded. Prolonged exposure of the propellant of these items to either high or low temperatures may increase the normal rate of deterioration or make them more susceptible to initiation or damage during handling. Such damage could result in uneven burning and dangerously high internal pressure during use.

3.4 REFERENCES

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4.0 DESIGN GUIDELINES

4.1 PART SELECTION/CONTROL

Designing reliability into a system requires the careful selection of the discrete parts that comprise the system. The objective of any part selection and control program is to obtain parts that will perform adequately and reliably during the designed service life of the equipment in which they will be used and that will be available at minimum cost whenever needed throughout the equipment's service life. This basic objective applies to all systems regardless of the amount of time the system will spend in a non-operating state.

The task of selecting, specifying, applying, and controlling the parts used in complex electronic systems is a major engineering undertaking. It requires a multidisciplinary approach involving the participation of component engineers, failure analysts, reliability engineers, and design engineers. Numerous controls, guidelines, and requirements must be developed, evaluated, and implemented, including the development of meaningful procurement specifications which reflect a balance among design requirements, quality assurance, and reliability needs. A list of general ground rules for a successful parts selection and control program is presented in Table 4.1-1.

The essentials of a successful part selection and control program are detailed in references 1 and 2 and will not be repeated here. They are applicable to all systems and should be followed to provide the framework for an effective program. The information presented in this section provides details concerning the selection and control of parts for systems that will spend a significant part of their service life in a non-operating state. Combining this information with the guidelines presented in references 1 and 2 will allow the tailoring of a part selection and control program meeting specific program needs.

Central to any successful part selection and control program is an understanding of the characteristics of the alternative parts for a given application and their respective failure modes and mechanisms in the anticipated operating and non-operating environments. Only by thoroughly understanding their strengths and weaknesses can a designer properly weigh the alternatives for a given application and arrive at effective tradeoff decisions that maximize performance and reliability at the least cost.

Table 4.1-1. Ground Rules for Part Selection and Control (Refs. 1,2)

A) Determine part type needed to perform the required function and the environment (operating and non-operating)in which it is expected to be used.

B) Determine part criticality.

- Does the part perform critical functions, i.e., safety or mission-critical?
- Does the part have limited life?
- Does the part have long procurement lead time?
- Is the part reliability sensitive?
- Is the part a high-cost item or does it require formal qualification testing?

C) Determine part availability.

- Is the part on a preferred list?
- Is the part a Standard MIL item available from a qualified vendor?
- What is the part's normal delivery cycle?
- Will the part continue to be available throughout the life of the equipment?
- Is there an acceptable in-house procurement document on the part?
- Are there multiple sources available?

D) Determine reliability level required for the part in its application, both operating and non-operating.

E) Select the appropriate burn-in or other screening methods for improving the part's failure rate (as required).

F) Prepare an accurate and explicit part procurement specification, where necessary. Specifications should include specific screening provisions, as needed, to assure adequate reliability.

G) Determine actual stress level of the part in its intended application. Include failure rate calculations.

H) Employ appropriate derating factors consistent with reliability prediction studies.

I) Determine need for non-standard part and prepare a request for approval as outlined in MIL-STD-965.

In a theoretical study of the possible failure mechanisms and material degradation processes that will cause electronic components to fail during long-term non-operating periods (Refs. 3,4), it was concluded that the most important environmental stresses during non-operating periods are mechanical, chemical, and low thermal. Since a non-operating environment is normally free from electrical stresses and the higher temperatures associated with operating devices, the chemical and physical stresses associated with electronic devices during non-operating periods are determined by the ambient conditions and materials within a package or assembly. The synergism of the three primary non-operating stresses is critical. While any one of the three acting alone may not be particularly damaging, the combined effect of two or three acting together increases the likelihood of device failure.

The two primary sources of mechanical stress during non-operating periods are inertial forces and thermal-mechanical interactions. Inertial forces occur from cyclical accelerations associated with vibrations and from transient accelerations related to shock from transportation and handling. Except for large components such as relays, transformers, connectors, and large hybrids, most electronic components have very small masses and are not particularly susceptible to damage from the inertial forces expected during non-operating periods.

Thermal-mechanical interactions introduce differential expansion between materials within a device and between subassemblies and interconnections, due to temperature changes. These stresses occur in electronic components and assemblies due to two closely related phenomena. First, the materials in an electronic component or assembly have different coefficients of linear expansion so that large stresses can result even from slow, uniform temperature variations. Second, temperature gradients within the same material can lead to differential displacements due to separate regions of the material being at different temperatures. Other effects associated with thermal-mechanical phenomena include residual mechanical stresses which usually exist in electronic device structures because oxides, nitrides, and metal films are grown and bonds are made at elevated temperatures and then cooled down to ambient conditions. (Refs. 3, 4)

Thermal shock is most critical for materials having high thermal impedance such as ceramics. While electronic equipment will be thermally cycled at various times during non-operating periods, the thermal mass of the equipment will prevent individual devices from experiencing rapid temperature changes. Previous studies (Refs. 3,4) have shown that the maximum temperature span for non-operating equipment in open field storage during a given day due to diurnal temperature cycling will be less than 70 degrees Celsius so that the rate of change will be less than 6 degrees Celsius per hour.

Chemical stresses develop in electronic devices from a large number of potential chemical interactions including solid-solid metallurgical processes as well as chemical reactions with external contaminants. The rate of degredation depends upon temperature and a number of metallurgical factors such as specific materials, microcracks, compositional variations, grain size, dislocation density, and impurities. Some of the more important sources of chemical stresses in electronic devices and assemblies during non-operating periods are as follows (Refs. 3, 4):

- Concentration gradients within device structures.
- Process chemicals remaining from fabrication steps.
- Gases evolved from device materials.
- Contaminants including moisture.
- Environmental gases introduced through deficiencies in hermetic seals.
- Stress accelerated chemical reactions.
- Galvanic cells.

The overwhelming area of concern for long-term non-operating reliability is the influence of chemical contaminants. A large number of contaminants have been found to cause failures in electronic devices, including halogen ions, alkali metal ions, residual process chemicals, hydrogen, oxygen, atmospheric pollutants and water. The thresholds for contaminant induced chemical reactions are generally unknown.

Moisture may be the single most important factor in long-term non-operating reliability and all possible steps should be taken to eliminate it within electronic devices and assemblies. The amount of water required to degrade the materials within a device package is known to be very small, and may be as little as one molecular layer. (Refs. 3, 4)

Most failures that occur during non-operating periods are of the same basic kind as those found in the operating mode, though precipitated at a slower rate. Furthermore, experience has also shown that most failures that occur during non-operating periods are the result of latent manufacturing defects rather than specific aging mechanisms.

These two facts have significant implications for the selection and control of parts for equipment that will spend a significant portion of its service life in a non-operating state. Since most failure modes for non-operating periods are the same as for operating periods, the same part selection and control measures used to achieve designs that exhibit high operating reliability will also achieve designs that exhibit high non-operating reliability. For example, the use of Established Reliability components instead of standard components or the use of Class S integrated circuits instead of Class B integrated circuits will result in both higher operating and non-operating reliability. In Reference 6, S.M. Cherkasky estimates that the number of failures during non-operating periods can be reduced by two-thirds to three-fourths by going from MIL-STD components to Established Reliability (ER) components. In addition, since most non-operating failures are the result of latent manufacturing defects such as identified in Table 4.1-2, screens that are effective in weeding out such defects will be effective in eliminating most non-operating failures.

Table 4.1-2. Typical Latent Manufacturing Defects Causing Failures During Non-Operating Periods (Ref. 5)

- Contamination of integrated circuits.
- Lifted bonds on transistors and integrated circuits.
- Electrolysis of nichrome metal film resistors due to entrapped moisture.
- Dielectric breakdown in ceramic capacitors.
- Electrolyte leakage in wet tantalum capacitors.
- Sealed in moisture that creates voids in nichrome film.
- Inadequate cleaning of ceramic loose cores causing flaking of nichrome elements.
- Loose conductive particles causing shorts in IC and hybrid packages.

This second point is not surprising since the generally lower thermal and electrical stress levels which occur during non-operating periods as compared to operating periods will tend to prolong the infant mortality period of the classical reliability bathtub curve. As shown in figure 4.1-1, this period, which is characterized by a rapidly decreasing failure rate as latent workmanship defects are worked out of a system, will continue for years for non-operating equipment as opposed to only a few weeks or months for operating equipment.

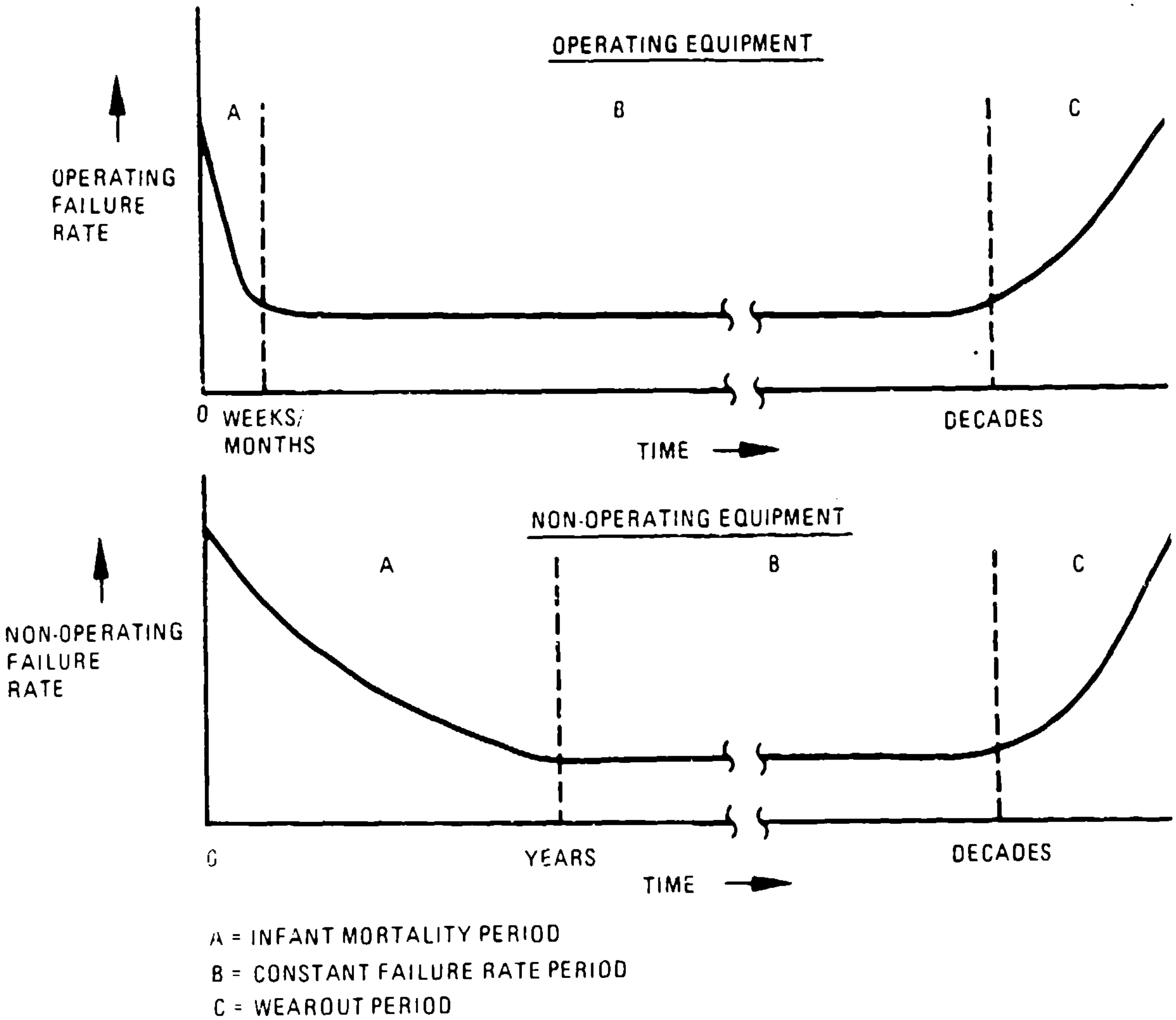

Figure 4.1-1. Operating vs. Non-Operating Equipment Reliability Bathtub Curves

The term "screen" as used here refers to the application of a stress test, or tests, to a device with the purpose of revealing inherent weaknesses (and thus incipient failures) of the device without destroying the integrity of the device. The rationale for such action is that the inferior devices will fail and the superior devices will pass, provided the tests and stress levels are properly selected. Of all of the factors that will reduce failure rates during non-operating periods, part screening is among those that accomplish it most effectively. (Ref. 6)

In summary, the failure mechanisms of greatest importance during non-operating periods are those related to latent manufacturing defects, corrosion processes, and mechanical fracture. Because of the absence of electrical stress, electrical or potential current induced degradation processes are not important during non-operating periods. Moisture within a device or assembly package is the most important factor for both corrosion and mechanically induced failures. Chemicals, including moisture trapped within a package due to improper cleaning or because of evolution from materials such as polymers, are also of great concern for long-term non-operating reliability. Thermal-mechanical stresses aided by chemical agents will cause cracks to propagate in seals, passivation layers, bonds, metallization layers, silicon chips, and other device structures.

Summarized in table 4.1-3 are general guidelines for selecting and controlling parts for use in equipment that will spend a significant part of its service life in a non-operating state. In addition to these general guidelines, the following sections provide specific part selection and control guidance.

4.1.1 Resistors

Resistors are functionally classified as fixed or variable. Resistor classifications are further subdivided into three basic groups defined by construction as described below: (Ref. 13)

- Composition resistors are made from a mixture of resistive material and a binder and are molded into a specific shape and resistive value.

- Film resistors consist of a resistive film deposited inside or outside an insulating cylinder.

- Wire-wound resistors are composed of a resistive wire wound on an insulating body

Special resistors, such as thermistors and network film resistors are constructed differently. A detailed description of these resistors is presented in section 4.1.1.3.

Table 4.1-3. General Part Selection/Control Guidelines for Dormant Equipment Design

General

- The most important environmental stresses during non-operating periods are mechanical, chemical, and low thermal. The synergism of these three stresses is critical.

- The failure mechanisms of greatest importance during non-operating periods are those related to latent manufacturing defects, corrosion processes, and mechanical fracture, with most failures being the result of latent manufacturing defects rather than specific aging mechanisms.

- Most failures that occur during non-operating periods are of the same basic kind as those found in the operating mode, though precipitated at a slower rate.

- Moisture is the single most important factor to long-term non-operating reliability. All possible steps should be taken to eliminate it within electronic devices.

- The same part selection and control measures used to achieve designs that exhibit high operating reliability will also achieve designs of high non-operating reliability.

Material Selection

- Materials for use within hermetically sealed enclosures should be selected for minimum outgassing of products detrimental to equipment and parts. Outgassing products can include moisture and potentially corrosive chemicals. Refer to reference 11 for a compilation of material outgassing data.

- Hygroscopic materials should be avoided or protected against accumulation of excess moisture. It has been found on tests that the moisture to be removed from the materials in dehumidification is from 5 to 200 times the net amount that must be taken form the air. (Ref. 12)

- Materials with non-porous surfaces are preferred for their resistance to entrapment of contaminants. Castings should be impregnated to prevent absorption of harmful materials.

- The settlement characteristics of hydraulic and other fluids over the non-operating period should be considered.

Table 4.1-3. General Part Selection/Control Guidelines for Dormant Equipment Design (Con't)

Material Selection Con't

- Avoid materials sensitive to cold flow and creep.
- Avoid metalized and non-metal finishes which have flaking characteristics.
- Consider age hardeni , and strain relief of materials and joints.
- In general, amorphous thermoplastics (particularly if plasticized) and polymers containing labile bonds (such as Thiokol polysulfide rubbers) exhibit very high stress relaxation (or creep) ratios and should be avoided.
- Avoid the use of lubricants. They migrate into undesirable locations and may outgas harmful products. If required, dry lubricants, such as graphite, are preferred.
- Do not use teflon gaskets. Teflon will flow under pressure resulting in seal loss after extended periods of time.
- Use silicone based rubber gaskets in lieu of conventional rubber gaskets. Silicone gaskets have superior flexibility retention over time and will not dry out, become brittle, or crack with aging as conventional rubber gaskets will.
- Do not use corrosive solder fluxes unless detailed cleaning procedures are specified along with appropriate verification meth s to ensure complete removal of residual contaminants.
- Do not use dissimilar metals, as defined by MIL-STD-889, in intimate contact with each other unless suitably protected against electrolytic corrosion as described in MIL-HDBK-729 and MIL-STD-889.

Table 4.1-3. General Part Selection/Control Guidelines for Dormant Equipment Design (Con't)

Part Selection

- Use parts that have demonstrated successful age histories and that have inherently good storage characteristics. Avoid parts which exhibit time-dependent deterioration.

- Do not use non-hermetically sealed semiconductors and microcircuits, such as plastic (organic or polymeric) encapsulated or sealed devices. (See sections 4.1.3 and 4.1.4.)

- Do not use semiconductors and microcircuits that contain nichrome-deposited resistors. They are suceptable to electrolysis with trace amounts of moisture and they are subject to deterioration and failure at contact interfaces with aluminum conductors due to interdiffusion.

- Do not use semiconductors and microcircuits with gold-aluminum systems that have not been determined to be free of "purple plague" problems.

- Select parts that use mono-metallization to avoid galvanic corrosion and other corrosion related problems.

- Do not seal chlorine or other halogen-containing materials within any circuitry components or assemblies because chlorine and other halogen ions can rapidly degrade electronic devices when moisture is present. Polymers used should be simple hydrocarbons or compounds of carbon, hydrogen, and oxygen. Nitrogen containing polymers should be considered with skepticism. Ammonia and amines from curing epoxy resins can react with ions to form complexes and with acids or water to form cations. Sulfur-cured rubbers and plasticized plastics can generate volatile sulfur and plasticizer compounds that attack not only plastics and rubbers but also certain metallic components (e.g. silver and copper contacts.).

- Do not use electronic parts/components employing polymers for package seal. Polymers will transmit moisture and other gases.

- Do not use wet electrolytic capacitors. (See section 4.1.2.1.4.)

Table 4.1-3. General Part Selection/Control Guidelines for Dormant Equipment Design (Con't)

Part Selection Con't

- Do not use variable resistors, potentiometers, variable capacitors, or variable inductors. (See sections 4.1.1.2, 4.1.2.2, and 4.1.5.)

- Avoid the use of electromechanical relays. (See section 4.1.6.2.)

- Where possible, avoid attachments and connections that depend on spring action for effectiveness, unless the spring is normally in its relaxed position.

- Use molded cables in preference to bundled wire runs to relieve stress in individual wires and to reduce the area available for moisture and other contaminant absorption.

- Do not use solid tantalum capacitors in circuit applications without at least 3 ohms/volt series resistance to limit current into the capacitor.

- Do not use non-hermetically sealed film capacitors. (See section 4.1.2.)

- Do not use prohibited parts identified in MIL-STD-454.

Evaluation/Control

- Part screening is among the most effective ways of reducing failures during non-operating periods.

- Particulate matter is one of the dominant concerns as a non-operating failure mechanism.

- Thermal shock should never be used as a screen test stress for hermetically sealed devices that will be in a non-operating state for long periods of time. The stresses induced by thermal shock can result in package seal failure over time.

- State-of-the-art technologies must be carefully evaluated for potential non-operating failure modes and mechanisms prior to use. Where sufficient field experience data is not available, accelerated aging tests and material compatability studies should be performed.

Dormancy is not a degradation factor for resistors, however, dormant resistors, especially dormant variable resistors may degrade due to environmental factors experienced during the dormant period. Moisture is the most significant degradation factor for non-operating resistors. Most resistors are encapsulated in a molded plastic case or are conformally coated to provide moisture protection, but no plastic is equivalent to hermetic sealing.

Shock and vibration are significant degrading environmental factors on variable resistors. Significant changes in resistance value may be induced by shock and vibration. Section 4.1.1.2 presents a more detailed examination of dormant variable resistors.

Listed below are several general resistor selection/control guidelines that are applicable to both operational and dormant resistors (Refs. 1, 13, 20, 21). Subsequent subsections present more detailed part selection/control guidelines for the various resistor categorizations. Tables 4.1.1.1-1 and 4.1.1.2-1 present a more detailed examination and corresponding guidelines for environmental effects on dormant resistors.

- Select a resistor for each application from the list of standard types and values. Established Reliability resistors have tighter reliability screening, process control, and failure-rate proof from cumulative life test data, and are therefore recommended for dormant applications whenever applicable.

- Select a resistor whose resistance value plus tolerance value plus voltage coefficient plus temperature coefficient plus drift with time are within the resistance requirements for the required application. For dormant applications, especially in extreme environmental conditions, the designer should consider designing for an end of life tolerance with a "buffer tolerance" added to the purchase tolerance to insure long life reliability.

- Various initial (purchase) tolerances are available depending on the type of resistor. The designer should realize that the initial accuracies become meaningless if the inherent stability of the resistor is not consistent with the basic accuracy requirements of the application.

- During dormancy, as well as during operation, any characteristic (i.e., resistance, power rating, size, etc.) of any resistor may change value as a result of stresses caused by the environmental effects of temperature, humidity, pressure, vibration, etc. Changes caused by environmental stresses may be linear or non-linear, reversible or non-reversible (permanent) or combinations thereof.

- Excessive temperature rise due to inadequate heat dissipation is the predominant cause of failure for operating resistors. Although, a dormant resistor does not experience the same amount of heat as an operating resistor, the same heat dissipation should be adhered to, because the dormant resistor will eventually be required to operate.

- Resistors which are closely mounted together in circuits can cause moisture and dirt traps. Moisture and dirt traps eventually form corrosive materials which can deteriorate resistors and other electronic parts. Moisture can accumulate around dirt even in an atmosphere of normal humidity. Normal humidity in dormant environment typically ranges from 40 to 70% relative humidity. Moisture (humidity, rain, snow, etc.) is the greatest enemy of dormant resistors. If dormant equipment is subjected to humid conditions it must be protected with adequate moisture protection, such as coatings. The designer should design dormant equipment with hermetically sealed components and conformally coated circuit boards in order to protect the equipment from moisture induced degradation. A more detailed examination of coatings, preservatives and packaging of dormant equipment is presented in section 4.5.

4.1.1.1 General Characteristics of Fixed Resistors

Fixed resistors are among the most stable electronic components in dormant or operational configurations. No major problems have been identified for fixed resistors in a dormant mode. The following sections present guidelines and general application information for fixed resistors in dormant modes. These subsections are subdivided by resistor construction type.

Table 4.1.1.1-1 summarizes environmental factors and effects, and presents guidelines for fixed resistors in a dormant mode; the table is categorized by the construction type of the resistors.

4.1.1.1.1 Fixed Composition Resistors

Fixed composition resistors consist of a mixture of finely divided carbon and a binder, either in the form of a slug or a heavy coating, on a glass tube. Specially formed wire leads are embedded in the resistance element. An insulating case, usually phenolic, is molded around the resistor forming a one-piece enclosure to support the leads and provide a moisture seal.

Like all plastics, the phenolic case is not completely impervious to moisture (Ref. 14). After long periods of dormancy in high humidity

Table 4.1.1.1-1. Environmental Effects/Guidelines for Dormant Fixed Resistors.

Environment	Composition	Film	Wire-Wound
Ambient (25 ±10°C and Relative Humidity < 90%)	No adverse effects anticipated on dormant devices	Resistance increase by 0.2% per year	No adverse affects anticipated on dormant wire-wounds
High Temperature	Resistance change of ± 15 % at maximum non-operating temperature 130°C[1]	Resistance change of ± 12% at maximum non-operating temperature 150°C[1]	Resistance change of ± 0.1% at maximum non-operating temperature 135°C[1]
	Probable poor lead solderability of inventoried units (not assembled into systems) due to oxidation and the growth of intermetallics.	Probable poor lead solderability of inventoried units (not assembled into systems) due to oxidation and the growth of intermetallics.	Probable poor lead solderability of inventoried units (not assembled into systems) due to oxidation and the growth of intermetallics.
Low Temperature	Resistance change of ± 2% at minimum non-operating temperature -55°C[1]	Resistance change of ± 0.25% at minimum non-operating temperature -55°C[1]	Resistance Change of ± 0.01% at minimum non-operating temperature -55°C[1]
Humidity (moisture precipitation, Relative Humidity > 90%)	Resistance change ± 15%	Resistance change ± 2%	Resistance change ± 0.2%
	Surface moisture may result in leakage paths which will lower the resistance value.	Corrosion or electrolytic action involving impurities in a major cause of open circuits in the film and end cap terminations.	Exposure to severe moisture can cause shunt paths on the resistor or shorts between the windings.
	Absorption of moisture into the element will increase the resistance.	Mositure absorbed during dormancy may not become apparent until after a period of operation with voltage applied to stimulate electrolysis.	Possible lead corrosion
	Possible lead corrosion		

Table 4.1.1.1-1. Environmental Effects/Guidelines for Dormant Fixed Resistors. (Continued)

Environment	Composition	Film	Wire-Wound
Humidity (moisture precipitation) (Continued)	For dormant applications use only hermetically sealed resistors. Whenever possible seal boards with conformal coatings.	Exposure to extreme moisture can cause shunt paths on the surface of the resistor. Possible lead corrosion.	
Low Pressure[2]	The differential between the internal and external pressure is increased. This puts added stress on seams and terminal seals and can result in subsequent rupture of the heremtic seal. Some materials will outgas at low pressures. The designer should consult Reference 11 to identify outgassing effects for low pressure applications.	The differential between the internal and external pressure is increased. This puts added stress on seams and terminal seals and can result in subsequent rupture of the heremtic seal. Some materials will outgas at low pressures. The designer should consult Reference 11 to identify outgassing effects for low pressure applications.	The differential between the internal and external pressure is increased. This puts added stress on seams and terminal seals and can result in subsequent rupture of the heremtic seal. Some materials will outgas at low pressures. The designer should consult Reference 11 to identify outgassing effects for low pressure applications.
Solar Radiation	No effect anticipated if absorbed radiation results in temperature below maximum. (See High Temperature). Possibly fade markings after extended exposure.	No effect anticipated if absorbed radiation results in temperature below maximum. (See High Temperature). Possibly fade markings after extended exposure.	No effect anticipated if absorbed radiation results in temperature below maximum. (See High Temperature). Possibly fade markings after extended exposure.

Table 4.1.1.1-1. Environmental Effects/Guidelines for Dormant Fixed Resistors. (Continued)

Environment	Composition	Film	Wire-Wound
	Extended UV radiation could degrade potting and thermo-plastic materials with the potential of reducing the seal integrity of the unit.	Extended UV radiation could degrade potting and thermo-plastic materials with the potential of reducing the seal integrity of the unit.	Extended UV radiation could degrade potting and thermo-plastic materials with the potential of reducing the seal integrity of the unit.
Wind	No data available, no adverse effects anticipated.	No data available, no adverse effects anticipated.	No data available, no adverse effects anticipated.
Shock[2]	Resistance change of $\pm$ 2%[1]	Resistance change of $\pm$ 0.5%[1]	Resistance changes of $\pm$ 0.2%[1]
Vibration (High Frequency)[2]	Resistance change of $\pm$ 2%[1]	Resistance change of $\pm$ 0.5%[1]	Resistance changes of $\pm$ 0.2%[1]
Sand and Dust	Can cause moisture traps, and introduce contaminants which will accelerate corrosive effects.	Can cause moisture traps, and introduce contaminants which will accelerate corrosive effects.	Can cause moisture traps, and introduce contaminants which will accelerate corrosive effects.
Salt Fog	Accelerated moisture effects (see Humidity).	Accelerated moisture effects (see Humidity).	Accelerated moisture effects (see Humidity).
Temperature Shock[2]	Resistance change of $\pm$ 4%[1]	Resistance change of $\pm$ 0.2%[1]	Resistance change of $\pm$ 1%[1]
Fungus	Not inherently susceptible to attach by fungus, however, contaminants may provide nutrients for fungus growth.	Not inherently susceptible to attach by fungus, however, contaminants may provide nutrients for fungus growth.	Not inherently susceptible to attach by fungus, however, contaminants may provide nutrients for fungus growth.

Table 4.1.1.1-1. Environmental Effects/Guidelines for Dormant Fixed Resistors. (Continued)

Environment	Composition	Film	Wire-Wound
Fungus (Continued)	Keep humidity below 50%; ideal conditions for fungus growth are 20 - 40°C and 85 - 100% relative humidity. Fungus can cause shorts and material deterioration.	Keep humidity below 50%; ideal conditions for fungus growth are 20 - 40°C and 85 - 100% relative humidity. Fungus can cause shorts and material deterioration.	Keep humidity below 50%; ideal conditions for fungus growth are 20 - 40°C and 85 - 100% relative humidity. Fungus can cause shorts and material deterioration.
Acoustic Noise	No data available, no adverse effects anticipated.	No data available, no adverse effects anticipated.	No data available, no adverse effects anticipated.
Gun Fire	See Shock, Vibration	See Shock, Vibration	See Shock, Vibration
Acceleration	See Shock, Vibration	See Shock, Vibration	See Shock, Vibration
Space	See Low Pressure, Nuclear Radiation	See Low Pressure, Nuclear Radiation	See Low Pressure, Nuclear Radiation
Electromagnetic Radiation	EMR, primarily lightning, is a more detrimental environment than EMP for dormant equipment, and may be used as a worst case when considering EMP and EMR effects. Generally, EMR has no direct effects on dormant resistors unless the resistors are close to the surface of dormant equipment that is not completely sealed and	EMR, primarily lightning, is a more detrimental environment than EMP for dormant equipment, and may be used as a worst case when considering EMP and EMR effects. Generally, EMR has no direct effects on dormant resistors unless the resistors are close to the surface of dormant equipment that is not completely sealed and	EMR, primarily lightning, is a more detrimental environment than EMP for dormant equipment, and may be used as a worst case when considering EMP and EMR effects. Generally, EMR has no direct effects on dormant resistors unless the resistors are close to the surface of dormant equipment that is not completely sealed and

Table 4.1.1.1-1. Environmental Effects/Guidelines for Dormant Fixed Resistors. (Continued)

Environment	Composition	Film	Wire-Wound
Electromagnetic Radiation (Continued)	grounded. Therefore, EMR effects on dormant resistors are application dependent, and typically no adverse effects are anticipated.	grounded. Therefore, EMR effects on dormant resistors are application dependent, and typically no adverse effects are anticipated.	grounded. Therefore, EMR effects on dormant resistors are application dependent, and typically no adverse effects are anticipated.
Electromagnetic Pulse	EMP has no direct effects on dormant resistors, however, wire runs near the external surfaces of dormant equipment (i.e., cables, antennas, data links, etc.) may be subject to EMP pickup resulting in surge currents. Generally, the surge currents associated with EMP are small due to narrow pulse width. Therefore, the secondary effect on resistors is application dependent, and no adverse effects are anticipated for dormant equipment. (See EMR).	EMP has no direct effects on dormant resistors, however, wire runs near the external surfaces of dormant equipment (i.e., cables, antennas, data links, etc.) may be subject to EMP pickup resulting in surge currents. Generally, the surge currents associated with EMP are small due to narrow pulse width. Therefore, the secondary effect on resistors is application dependent, and no adverse effects are anticipated for dormant equipment. (See EMR).	EMP has no direct effects on dormant resistors, however, wire runs near the external surfaces of dormant equipment (i.e., cables, antennas, data links, etc.) may be subject to EMP pickup resulting in surge currents. Generally, the surge currents associated with EMP are small due to narrow pulse width. Therefore, the secondary effect on resistors is application dependent, and no adverse effects are anticipated for dormant equipment. (See EMR).
Nuclear Radiation	The most radiation sensitive resistor type. Resistance usually decreases under neutron and gamma radiation.	Less susceptible to radiation damage than carbon composition. Exposures up to 2×10^{13} protons/cm^2 produce no permanent effects.	Wire-wound resistors are the most stable of all electronic components with respect to steady state nuclear radiation damage. One experiment showed a maximum

Table 4.1.1.1-1. Environmental Effects/Guidelines for Dormant Fixed Resistors. (Continued)

Environment	Composition	Film	Wire-Wound
	Humidity and temperature changes obscure damage from nuclear radiation.	Different manufacturing techniques result in different degradation levels. (Ref. 15, 16, 17)	resistance change of 0.8% during exposure to 1.8×10^8 fast neutrons/cm^2 with no permanent effects observed.
	Change in resistance is a function of resistance value as well as of integrated neutron flux. 100 ohm resistors in a radiation environment of 2.3×10^9 fast neutrons/cm^2 and gamma fluxes of 3.9×10^4 ergs/g (C) had a maximum resistance deviation estimated at approximately -1.7%. One megohm resistors changed approximately -6.8%. Resistors between 100 ohms and 1 megaohm fall within these percentages. (Refs. 15, 16, 17.)	100 ohm carbon film resistors in a radiation environment of 2.4×10^9 fast neutrons/cm^2 and gamma fluxes of 4×10^4 ergs/g (C) had a maximum resistance deviation estimated at approximately +0.9%. One megaohm resistors changed approximately +2.9%. Resistors having values between 100 ohms and 1 megaohm fell within these percentages. (Refs. 15, 16, 17).	Burst effects data on wire-wound resistors is extremely limited. Preliminary data show changes in resistance of approximately 22% observed in a gamma radiation pulse (approx. 150 microseconds) of 8×10^9 ergs/g(C) sec. Oddly enough the most radiation resistant component appears most sensitive to radiation bursts. (Refs. 15, 16, 17.)

1 Deviations are worst case estimates for dormant equipment. Actual deviations may be less severe; refer to applicable MIL specification. Worst case deviations were provided as recommended design tolerances to insure long term reliability in dormant equipment.

2 As per applicable Military specification ratings.

the resistance value can change appreciably from absorbed moisture. Moisture may have two effects on the resistance value: surface moisture may result in leakage paths which will lower the resistance value or absorption of moisture into the element may increase the resistance. This is a reversible process which can be counteracted by heat from periodic operation or from high ambient temperature. A reverse effect is also observable. Composition resistors can lose moisture resulting in increased resistance after long periods of storage at low humidity (Ref. 18).

Although composition resistors are characterized by large resistance changes with time, moisture, and temperature, open and short circuit failure modes seldom occur (Ref. 14).

Generally, carbon composition resistors are the least stable resistor type in dormant applications, but with adequate environmental protection no dormancy induced problems are anticipated. Detailed environmental factors and guidelines are presented in table 4.1.1.1-1.

4.1.1.1.2 Fixed Film Resistors

Fixed film resistors usually consist of resistive material, carbon or metal, deposited on the inside or outside of glass or refractory tubes and spirally-cut to achieve specific resistance. Leads in the end of the tubes and various types of end caps provide connection to the resistance element. As with fixed composition resistors, a molded plastic case provides physical strength and a moisture seal (Ref. 14).

The effect of moisture on film resistors varies according to the manufacturing technique. Properties of materials used in the resistive film can be controlled to provide low thermal coefficients (on the order of 50 ppm/deg C) and good moisture protection (Ref. 18).

Corrosion or electrolytic action involving impurities or surface contaminants can be a cause of open circuits in the film or between the film and end cap connections. Reduced resistance from this effect prior to malfunction can be hard to detect because of the common localized nature of the effect. Moisture absorbed during storage does not cause serious trouble until after a period of operation with voltage applied to stimulate electrolysis.

Manufacturing defects have been found to be the primary cause of failures for nonoperating film resistors. Increased resistance, decline in insulation resistance, and eventual opens from defective seals, swelling of binder from moisture, corrosion of terminal connections and oxidation of metals have been found to be the most common failure modes for film resistors in the dormant state. Tighter screening and process control can be used to identify latent manufacturing defects which may induce these failures in dormant fixed film resistors.

MIL-R-55342 are fixed film chip established reliability resistors. They are primarily intended for incorporation into hybrid micro-circuits. They are uncore, leadless chip devices which exhibit high stability with respect to time even under severe environmental conditions. These resistors are essentially unaffected by moisture. Under low humidity conditions these resistors may be prone to sudden significant changes in resistance (usually reduction in value), and significant changes in temperature coefficient of resistance as a result of static discharge during handling, packaging, or shipment. Substitution of more suitable implements and materials can help minimize this problem. For example, use of cotton gloves, static eliminator devices, humidifiers, and operator and work bench grounding systems can reduce static buildup during handling. Means of alleviating static problems during shipment include elimination of loose packaging of resistors and use of metal foil and anti-static (partly conducting) plastic packaging materials. A primary failure mode for chip resistors is package fatigue from temperature cycling. The designer must be sure to match the temperature coefficient of chip resistors with the substrate to preclude stress fatigue failures from temperature cycling during dormant storage.

Film resistors are more stable than composition resistors and approach may of the good characteristics of the larger and more expensive wire-wound types. Because of their stability, even under extreme environmental conditions, fixed film resistors are recommended for dormant applications. Environmental factors and guidelines for film resistors are presented in greater detail in table 4.1.1.1-1.

4.1.1.1.3 Fixed Wire-Wound Resistors

Wire-wound resistors are formed by winding a special alloy resistance wire on a ceramic form having expansion coefficients matched to that of the wire. By selecting and matching the resistance wire, almost any temperature coefficient of resistance can be obtained. Precision wire-wound resistors provide closer tolerance and better resistance stability that any other type of resistor. These resistors are generally well sealed in molded cases for use in high humidity environments.

The reliability characteristics of precision wire-wound resistors vary considerably with the resistance range. Low values of resistance can be formed with single layer windings for minimum inductance and other optimized characteristics. High resistance values require multiple layers with resultant problems of shorts between layers, higher mutual inductance, and physical disadvantages such as size and weight. Very low resistance values can also cause reliability problems because of the practical problems of close tolerances on short lengths of resistance wire. Specification limits on tolerance and resistance should be carefully observed.

Power wire-wound resistors are similar in construction to precision wire-wound types but less attention is given to close tolerances and noninductive winding. Greater attention is given to the means of mounting for the extraction of heat. Special silicone coatings are designed for maximum heat conduction and radiation. As with other wire-wound resistors, reliability is related to resistance range. Used to obtain high resistance, multiple layers of wire generate hot spots which are difficult to cool.

Moisture in wire-wound resistors is frequently a cause for leakage between turns and between layers which ultimately results in insulation breakdown and shorts. Corrosion and electrolytic action results in openings between resistor wire and end cap terminations (Ref. 15).

Opens can be caused in wire-wound resistors by defective wire and/or terminations. Opens can also be caused by corrosion resulting from moisture entering the resistor through poor seals or porous coatings. (Ref. 20)

Higher value wire-wound resistors are subject to mechanical damage resulting from vibration, shock, and pressure. This is because of the construction of the wire-wound and its size. Wire-wounds are typically constructed with a Plastic or ceramic bobbin with multiple layers of wire in the larger sizes. The fragile bobbin and extra weight may result in damage due to the mechanical factors.

Generally, wire-wounds are the most stable resistor with respect to environments and time. Failures in the dormant mode are usually due to manufacturing defects. Tighter screening and process control can be used to identify latent manufacturing defects which may induce failures in dormant fixed wire-wound resistors. Because of their stability, even under extreme environmental conditions, fixed wire-wound resistors are preferred for dormant applications. Environmental factors and guidelines for wire-wound resistors are presented in greater detail in table 4.1.1.1-1.

4.1.1.2 <u>Variable Resistors</u>

Generally, variable resistors are highly unstable devices, and they are not recommended for dormant applications. Tolerances of variable resistors reflect their instability. Periodic inspection is required to ensure that variable resistors are maintained within their resistance values. This will impact the maintenance concept selected for the dormant equipment. Refer to section 4.3 (Maintainability Design) of this text for a more detailed discussion of maintainability design guidelines for dormant equipment.

Environmental degradation is a significant failure mode for variable resistors. Variable resistors are highly susceptible to moisture, temperature, shock, vibration, and contaminant induced failures. Variable resistors cannot be sealed in a complete encapsulated jacket. Even when the resistor element is encased in a plastic or vitreous case there must be a portion of each turn exposed for contact with the wiper arm. This provides many possible points for the entrance of moisture and contaminants.

Variable resistors have movable shafts which protrude through the case and possibly through the front panel of equipment. This opens the interior of the variable resistor and Possibly the interior of equipment to the environment exterior. Various types of shaft seals, such as elastomer '0' rings can be used to protect the resistor interior, but they are imperfect seals (Ref. 18).

Dormant variable resistors should not be lubricated with a liquid lubricant, because the presence of oil lubricants can collect dust and other potentially corrosive and degradative contaminants.

When the use of variable resistors is required, they should be maintained in an enclosed unit to protect the interior of the resistor mechanisms from degrading environmental influences. The following subsections present design guidelines for variable resistors when they are absolutely required in dormant equipment. The subsections have been divided by precision type of the resistor.

Table 4.1.1.2-1 summarizes environmental factors and effects, and presents guidelines for variable resistors in a dormant mode.

4.1.1.2.1 Low Precision Variable Composition Resistors

These resistors are constructed in a similar fashion to fixed composition resistors. Many tapers can be obtained, but nonlinear conformity and stability characteristics are the least stable of all variable resistors with respect to time. These resistors have been known to have an average resistance change of +20 percent per year under ambient storage conditions. (Ref 13) The designer must insure that a design is capable of tolerating this significant resistance change if the design will spend significant periods in storage.

Table 4.1.1.2-1. Environmental Effects/Guidelines for Dormant Variable Resistors.

Environment	Composition	Film	Wire-Wound
Ambient (25 ± 10°C and relative humidity < 90%)	An average resistance change of +20% per year is estimated.	See Humidity	Sec Humidity
High Temperature	Resistance change of ± 15% at maximum non-operating temperature 120°C[1]	Resistance change of ± 10% at maximum non-operating temperature 125°C[1]	Resistance change of ± 5% at maximum non-operating temperature 150°C (105°C for low temperature MIL-R-19)[1]
	Probable poor lead solderability of inventoried units (not assembled into systems) due to lead oxidation and the growth of intermetalics.	Probable poor lead solderability of inventoried units (not assembled into systems) due to lead oxidation and the growth of intermetalics.	Probable poor lead solderability of inventoried units (not assembled into systems) due to lead oxidation and the growth of intermetalics.
	Probable poor adhesion of lead plating.	Probable poor adhesion of lead plating.	Probable poor adhesion of lead plating.
Low Temperature	Resistance change of ± 2% at minimum non-operating temperature -55°C[1]	Resistance change of ± 2% at minimum non-operating temperature -55°C[1]	Resistance change of ± 5% at minimum non-operating temperature -55°C[1]
	Possible thermo-plastic housing degradation with prolonged exposure, with potential cracking resulting in reduction of seal integrity.	Possible thermo-plastic housing degradation with prolonged exposure, with potential cracking resulting in reduction of seal integrity.	Possible thermo-plastic housing degradation with prolonged exposure, with potential cracking resulting in reduction of seal integrity.

Table 4.1.1.2-1. Environmental Effects/Guidelines for Dormant Variable Resistors. (Continued)

Environment	Composition	Film	Wire-Wound
Low Pressure[2]	The differential between the internal and external pressure becomes greater when external pressure is reduced. This puts added stress on seams and terminal seals and can result in subsequent rupture of the hermetic seal. Some materials will outgas at low pressures. The designer should consult Reference 11 to identify outgassing effects for low pressure applications.	The differential between the internal and external pressure becomes greater when external pressure is reduced. This puts added stress on seams and terminal seals and can result in subsequent rupture of the hermetic seal. Some materials will outgas at low pressures. The designer should consult Reference 11 to identify outgassing effects for low pressure applications.	The differential between the internal and external pressure becomes greater when external pressure is reduced. This puts added stress on seams and terminal seals and can result in subsequent rupture of the hermetic seal. Some materials will outgas at low pressures. The designer should consult Reference 11 to identify outgassing effects for low pressure applications.
Humidity (moisture, precipitation, relative humidity > 90%)	Not recommended for dormancy application in humid environments. Resistance will increase as a result of defective seals, resulting in moisture absorption, which causes swelling of the binders.	Not recommended for dormancy application in humid environments.	Not recommended for dormancy application in humid environments.
Solar Radiation	No adverse effects anticipated if absorbed radiation results in temperature below maximum. (See High Temperature)	No adverse effects anticipated if absorbed radiation results in temperature below maximum. (See High Temperature)	No adverse effects anticipated if absorbed radiation results in temperature below maximum. (See High Temperature)

Table 4.1.1.2-1. Environmental Effects/Guidelines for Dormant Variable Resistors. (Continued)

Environment	Composition	Film	Wire-Wound
Solar Radiation (Continued)	Possibly fade markings after extended exposure.	Possibly fade markings after extended exposure.	Possibly fade markings after extended exposure.
	Extended UV radiation could degrade potting and thermo-plastic materials with the potential of reducing the seal integrity of the unit.	Extended UV radiation could degrade potting and thermo-plastic materials with the potential of reducing the seal integrity of the unit.	Extended UV radiation could degrade potting and thermo-plastic materials with the potential of reducing the seal integrity of the unit.
Wind	No data available, no adverse effects anticipated.	No data available, no adverse effects anticipated.	No data available, no adverse effects anticipated.
Shock[2]	Resistance change of $\pm$ 2%[1]	Resistance change of $\pm$ 1%[1]	Resistance change of $\pm$ 1%[1]
Vibration	Resistance change of $\pm$ 2%[1]	Resistance change of $\pm$ 1%[1]	Resistance change of $\pm$ 5%[1]
Sand and Dust	Can cause moisture traps and introduce contaminants resulting in accelerated corrosion.	Can cause moisture traps and introduce contaminants resulting in accelerated corrosion.	Can cause moisture traps and introduce contaminants resulting in accelerated corrosion.
Salt Fog	Accelerated moisture effects.	Accelerated moisture effects.	Accelerated moisture effects.
Temperature Shock[2]	Resistance change of $\pm$ 15%[1]	Resistance change of $\pm$ 10%[1]	Resistance change of $\pm$ 5%[1]
Fungus	Not inherently susceptible to attach by fungus, however, contaminants may provide nutrients for fungus growth.	Not inherently susceptible to attach by fungus, however, contaminants may provide nutrients for fungus growth.	Not inherently susceptible to attach by fungus, however, contaminants may provide nutrients for fungus growth.

Table 4.1.1.2-1. Environmental Effects/Guidelines for Dormant Variable Resistors. (Continued)

Environment	Composition	Film	Wire-Wound
Fungus (Continued)	Keep humidity below 50%; ideal conditions for fungus growth are 20 - 40°C and 85 - 100% relative humidity. Fungus can cause shorts and material deterioration.	Keep humidity below 50%; ideal conditions for fungus growth are 20 - 40°C and 85 - 100% relative humidity. Fungus can cause shorts and material deterioration.	Keep humidity below 50%; ideal conditions for fungus growth are 20 - 40°C and 85 - 100% relative humidity. Fungus can cause shorts and material deterioration.
Acoustic Noise	No data available, no adverse effects anticipated.	No data available, no adverse effects anticipated.	No data available, no adverse effects anticipated.
Gun Fire	See Shock and Vibration	See Shock and Vibration	See Shock and Vibration
Acceleration	See Shock and Vibration	See Shock and Vibration	See Shock and Vibration
Space	See Low Pressure, Nuclear Radiation	See Low Pressure, Nuclear Radiation	See Low Pressure, Nuclear Radiation
Electromagnetic Radiation	EMR, primarily lightning, is a more detrimental environment than EMP for dormant equipment, and may be used as a worst case when considering EMP and EMR effects. Generally, EMR has no direct effects on dormant resistors unless the resistors are close to the surface of dormant equipment that is not completely sealed and grounded. Therefore, EMR effects on dormant resistors are application dependent, and typically no adverse effects are anticipated.	EMR, primarily lightning, is a more detrimental environment than EMP for dormant equipment, and may be used as a worst case when considering EMP and EMR effects. Generally, EMR has no direct effects on dormant resistors unless the resistors are close to the surface of dormant equipment that is not completely sealed and grounded. Therefore, EMR effects on dormant resistors are application dependent, and typically no adverse effects are anticipated.	EMR, primarily lightning, is a more detrimental environment than EMP for dormant equipment, and may be used as a worst case when considering EMP and EMR effects. Generally, EMR has no direct effects on dormant resistors unless the resistors are close to the surface of dormant equipment that is not completely sealed and grounded. Therefore, EMR effects on dormant resistors are application dependent, and typically no adverse effects are anticipated.

Table 4.1.1.2-1. Environmental Effects/Guidelines for Dormant Variable Resistors. (Continued)

Environment	Composition	Film	Wire-Wound
Electromagnetic Pulse	EMP has no direct effects on dormant resistors, however, wire runs near the external surfaces of dormant equipment (i.e., cables, antennas, data links, etc.) may be subject to EMP pickup resulting in surge currents. Generally, the surge currents associated with EMP are small due to narrow pulse width. Therefore, the secondary effect on resistors is application dependent, and no adverse effects are anticipated for dormant equipment. (See EMR).	EMP has no direct effects on dormant resistors, however, wire runs near the external surfaces of dormant equipment (i.e., cables, antennas, data links, etc.) may be subject to EMP pickup resulting in surge currents. Generally, the surge currents associated with EMP are small due to narrow pulse width. Therefore, the secondary effect on resistors is application dependent, and no adverse effects are anticipated for dormant equipment. (See EMR).	EMP has no direct effects on dormant resistors, however, wire runs near the external surfaces of dormant equipment (i.e., cables, antennas, data links, etc.) may be subject to EMP pickup resulting in surge currents. Generally, the surge currents associated with EMP are small due to narrow pulse width. Therefore, the secondary effect on resistors is application dependent, and no adverse effects are anticipated for dormant equipment. (See EMR).
Nuclear Radiation	The most radiation sensitive resistor type.	Less susceptible to radiation damage than carbon composition.	Wire-wound resistors are the most stable of all electronic components with respect to steady state nuclear radiation damage.
	Resistance usually decreases under neutron and gamma radiation.	Exposures up to 2×10^{13} protons/cm^2 produce no permanent effects.	One experiment showed a maximum
	Humidity and temperature changes obscure damage from nuclear radiation.	Different manufacturing techniques result in different degradation levels. (Ref. 15, 16, 17)	resistance change of 0.8% during exposure to 1.8×10^8 fast neutrons/cm^2 with no permanent effects observed.

Table 4.1.1.2-1. Environmental Effects/Guidelines for Dormant Variable Resistors. (Continued)

Environment	Composition	Film	Wire-Wound
Nuclear Radiation (Continued)	Change in resistance is a function of resistance value as well as of integrated neutron flux. 100 ohm resistors in a radiation environment of 2.3×10^9 fast neutrons/cm^2 and gamma fluxes of 3.9×10^4 ergs/g (C) had a maximum resistance deviation estimated at approximately -1.7%. One megohm resistors changed approximately -6.8%. Resistors between 100 ohms and 1 megaohm fall within these percentages. (Refs. 15, 16, 17.)	100 ohm carbon film resistors in a radiation environment of 2.4×10^9 fast neutrons/cm^2 and gamma fluxes of 4×10^4 ergs/g (C) had a maximum resistance deviation estimated at approximately +0.9%. One megaohm resistors changed approximately +2.9%. Resistors having values between 100 ohms and 1 megaohm fell within these percentages. (Refs. 15, 16, 17).	Burst effects data on wire-wound resistors is extremely limited. Preliminary data show changes in resistance of approximately 22% observed in a gamma radiation pulse (approx. 150 microseconds) of 8×10^9 ergs/g(C) sec. Oddly enough the most radiation resistant component appears most sensitive to radiation bursts. (Refs. 15, 16, 17.)

1 Deviations are worst case estimates for dormant equipment. Actual deviations may be less severe; refer to applicable MIL specification. Worst case deviations were provided as recommended design tolerances to insure long term reliability in dormant equipment.

2 As per applicable Military specification ratings.

The maximum operating temperature for these devices is 120 deg. C, and the maximum storage temperature is 70 degrees C.

Purchase tolerance is typically 10% for these devices.

4.1.1.2.2 Semi-Precision Variable Resistors

These are wire-wound, medium power variable resistors. The bodies and cores of RA style devices are constructed of phenolic or other plastic which may char or distort at high heat or crack under thermal shock. The RA style is moderately hygroscopic and thus more susceptible to moisture than either the RR or RP styles.

Purchase tolerance is typically 10% for these devices. These devices are more stable than the low precision variable resistors, but they are not recommended for application in a dormant environment, especially moist environments.

4.1.1.2.3 Precision Variable Resistors

There are two types of precision variable resistors available. A wire-wound, which has better stability and a non-wire-wound type. Both types offer a reasonable stability with respect to time for variable resistors. The wire-wound is typically available with a purchase tolerance of 5%, while the non-wire-wound is 10%. The wire-wound offers greater stability with respect to time in a dormant mode, but both types are the best suited variable resistors for a dormant environment.

4.1.1.2.4 Variable Non-Wire-Wound Trimmer Resistors

These trimmer resistors come in several different non-wire-wound construction types and styles. The stability with respect to time is comparable to corresponding wire-wound trimmers, but the non-wire-wounds are generally less expensive than the wirewounds. These trimmers are typically available with a purchase tolerance of 10%.

4.1.1.2.5 Variable Wire-Wound Trimmer Resistors

Wire-wound trimmer resistors offer good stability with respect to time in the dormant mode. These trimmers are very similar to non-wirewound trimmer resistors, but they are more expensive. They are typically available with a purchase tolerance of 10%.

4.1.1.3 Special Resistors

Two types of special resistors are considered in this section: Fixed Film Network resistors and thermistors. The fixed film network resistors are similar in construction to fixed film resistors, except that they are in a network configuration and are packaged in a dual-in-line package or flat pack configuration. Thermistors are resistors whose resistive elements are sensitive to temperature.

4.1.1.3.1 Fixed Film Network Resistors

These resistors are in a resistor network configuration having a film resistance element and are packaged in a dual-in-line package or flat pack configuration. These resistors are stable with respect to time, temperature, and humidity. Maximum ambient temperature for these devices in storage is 125 degrees C. Network resistors typically offer a very tight purchase tolerance of + .5%. Temperatures above the rated full load and storage maximums will cause temporary changes in resistance.

These resistors are particularly applicable to dormant environments, but only if extreme temperature changes above or below the rated maximums are not anticipated. Network resistors offer good stability, long life, and accuracy. They are particularly desirable where miniaturization is important, and where a number of the same resistor values are used in a circuit. Using networks in dormant circuits, instead of a configuration of several of the same value resistors, will reduce the possibility of moisture and contaminant buildup between resistors.

Network film resistors are similar in construction to fixed film resistors, and they experience the same environmental degradations. See table 4.1.1.1-1 for environmental effects/guidelines for fixed film resistors.

4.1.1.3.2 Thermistors

Thermistors are a mixture of metal oxides fired at high temperatures. Thermistors are manufactured in three distinct forms: beads, disks or washers and rods. The metal oxides are mixed in proportions to provide the required specific resistance and temperature coefficient for the particular application. The final product is a hard ceramic material which can be mounted in a variety of ways depending upon the mechanical, thermal, and electrical requirements.

Measurements of electrical parameters which describe thermal characteristics of the thermistor are difficult to perform accurately because of the element's complex construction, physical shape, sensitivities to ambient temperature, and direct heating effects of measurement currents. Such parameters as current-voltage relations as a function of temperature, electrical resistance at a fixed temperature, presence of hysterisis during temperature cycling, semiconductor indications, and changes in material constants are frequently measured to point out weaknesses caused by some adverse envirormental condition.

4.1.2 Capacitors

Capacitors are functionally classified as fixed or variable. These functional classifications are further subdivided by construction type as follows:

Fixed

- Paper and/or plastic
- Mica or glass
- Ceramic
- Electrolytic

Variable

- Ceramic
- Air

These basic types differ from each other in size, cost, capacitance, and general characteristics. Some are better than others for a particular application while no one type has all of the best characteristics. The choice among them, therefore, depends on the requirements (both initial and long term), the environment in which they must exist, and other factors. The designer should refer to MIL-STD-198E (Ref 22) and the applicable military specifications for a more detailed description of the various types of capacitors and their appropriate uses. The following sections present a more detailed examination of dormancy effects and guidelines for capacitors in various environments. Section 4.1.2.1 and subsections present a more detailed examination of fixed capacitor types, and section 4.1.2.2 presents variable capacitor types.

Generally, capacitors are stable devices in dormant applications, with several notable exceptions. The most notable exception is variable capacitors. Variable capacitors are highly susceptible to environmental induced degradations, and are therefore not recommended for dormant applications. Electrolytic capacitors, both liquid and solid types experience definite dormancy induced degradations, and use of these devices in dormant applications should be controlled.

For other capacitor types, dormancy is not a significant degradation factor, however, dormant capacitors may degrade due to environmental factors experienced during the dormant period.

As with resistors, temperature and moisture are the primary degrading environments for capacitors. Typically, a dormant capacitor is not subjected to the high temperatures experienced by an operating capacitor. Low temperature can result in significant capacitance changes for capacitors, whether they are operating or dormant. For low and high temperature, the designer should consult MIL-STD-198E (Ref 22) and the applicable MIL specs to determine capacitance deviations.

Capacitors are susceptible to moisture induced degradations. Even, in hermetically sealed units, moisture present during manufacture can lead to deterioration of insulation or dielectric materials. This can be a more serious consideration in certain lower grad devices. The entrance of moisture through cracks in the seals can be minimized i several ways. Capacitors with seal cracks prior to installation in equipment should be screened out and removed from manufacturing stock. Cracks developed during assembly into equipment can be prevented by careful process control and can be screened out by final assembly inspection. Cracks which develop during use in later life of the equipment can be traced to low-quality seals or stresses placed on the leads during equipment manufacture. Certain seal cracks are traceable to a combination of these causes plus stress resulting from shock and vibration, pressure, and other environments. Environmental effects and guidelines for dormant capacitors are presented in greater detail in table 4.1.2.1-1.

Listed below are several general capacitor selection/control guidelines that are applicable to both operational and dormant capacitors. Subsequent subsections present more detailed part selection/control guidelines for the various capacitor types in dormant applications.

- Select a capacitor for each application from the list of standard types and values. Established Reliability capacitors have tighter reliability screening, process control, and failure proof from cumulative life test data, and are therefore recommended for dormant applications whenever applicable.

- Various initial (purchase) tolerances are available depending of the type of capacitor. The designer should realize that the initial accuracies become meaningless if the inherent stability of the capacitor is not consistent with the basic accuracy requirements of the application. The capacitance tolerance that the designer uses in order to design a circuit which will operate satisfactorily for the required time requires consideration of: (1) acceptable tolerances according to specification; (2) capacitance-temperature characteristics; (3) capacitance-voltage characteristics; (4) retrace characteristics; (5) capacitance-frequency characteristics; (6) dielectric absorption; (7) capacitance as a function of pressure, vibration, and shock; and (8) capacitor aging in the circuit during storage.

- During dormancy, as well as during operation, any characteristic (i.e., capacitance, capacitance-frequency characteristics, size, etc.) of any capacitor may change value as a result of stresses caused by environmental effects. Changes caused by environmental stresses may be linear or non-linear, reversible or non-reversible (permanent) or combinations thereof. For dormant applications, especially in extreme environmental conditions, the designer should consider designing for an end of life tolerance with a "buffer tolerance" added to the purchase tolerance to insure long life reliability.

- The use of the self-healing properties of certain types of capacitors may not be desirable in circuits where intermittent failures and noise would be troublesome. Self-healing characteristics should be closely monitored in order to insure long life reliability.

- Oil or liquid filled capacitors should not be subjected to severe mechanical stresses (i.e., shock and vibration, low pressure, etc.). Leakage of the fluid can destroy the capacitor as well as adjacent components.

- Moisture in the capacitor dielectric will decrease the dielectric strength, life, and insulation resistance, and increase the power factor of the capacitor. In general, capacitors which operate in high humidities should be hermetically sealed. The effect of moisture on pressure contacts which are not gas tight may result in a high resistance or open contact.

- Capacitors which are closely mounted together in circuits can cause moisture and dirt traps. Moisture and dirt traps eventually form corrosive materials which can deteriorate capacitors and other electronic parts. Moisture can accumulate around dirt even in an atmosphere of normal humidity. Normal humidity in a dormant environment typically ranges from 40 to 70% relative humidity. Moisture (humidity, rain, snow, etc.) is the greatest enemy of dormant capacitors. If dormant equipment is subjected to humid conditions it must be protected with adequate moisture protection, such as coatings. The designer should design dormant equipment with hermetically sealed components and conformally coated circuit boards in order to protect the equipment from moisture induced degradation. A more detailed examination of coatings, preservatives and packaging of dormant equipment is presented in section 4.5.

4.1.2.1 General Characteristics of Fixed Capacitors

Generally, fixed capacitors are very stable components in either dormant or operational configurations. The only exceptions are electrolytic capacitors, which have been known to experience definite dormancy induced degradations. The self-healing properties of electrolytic devices will compensate for dormancy induced degradations during short dormancy periods (< 4 years). However, even during short non-operational periods these devices require periodic monitoring to insure reliable operation.

The following sections present a more detailed examination of the various types of fixed capacitors. Table 4.1.2.1-1 summarizes environmental factors and effects, and presents guidelines for fixed capacitors in a dormant mode.

4.1.2.1.1 Fixed Paper and Plastic Film Dielectric Capacitors

Capacitors with paper, paper/plastic, or plastic dielectrics are made by interleaving thin films of dielectric material with metallic foils which serve as electrodes. The resulting four-layer wedge is spiral wound into a tight cylindrical roll. Leads are attached to this capacitor section by soldering or welding. This capacitor type includes a wide variety of dielectric systems, styles, voltage ratings and temperature characteristics. Continuing developments in dielectric materials, construction techniques and manufacturing processes have resulted in a highly versatile family of devices. As a group they have high insulation resistance, good stability, low dielectric absorption and low loss factor over wide temperature ranges.

Metallized paper capacitors have low insulation resistance and are prone to dielectric breakdown. Plastic dielectric capacitors have superior moisture characteristics in that they are non-absorbent. All units should be hermetically sealed. Small amounts of moisture can increase the rate of chemical reactions within the caPacitor materials.

For metallized paper and plastic capacitors, where the conducting plates have thicknesses in the micrometer or submicrometer range, a

Table 4.1.2.1-1. Environmental Effects/Guidelines for Dormant Fixed Capacitors.

Environment	Paper/Plastic	Mica/Glass	Ceramic	Electrolytic
High Temperature[1]	Capacitance increase of +5% at maximum dormancy temperature 85°C.[2]	Capacitance decrease of -0.5% at maximum dormancy temperature 85°C.[2]	Capacitance deviations of ± 2% at maximum dormancy temperature of 85°C.[2]	Tantalum capacitors increase +50% in capacitance at 85°C.[2]
				Aluminum capacitors increase +15% in capacitance at 85°C.[2]
	The service life of the capacitor will decrease with an increase in temperature. One of the factors affecting wear out of a capacitor is dielectric degradation resulting from chemical activity with time.	The service life of the capacitor will decrease with an increase in temperature. One of the factors affecting wear out of a capacitor is dielectric degradation resulting from chemical activity with time.	The service life of the capacitor will decrease with an increase in temperature. One of the factors affecting wear out of a capacitor is dielectric degradation resulting from chemical activity with time.	Extended periods of high temperature may cause shorts in aluminum or tantalum capacitors.
	The insulation resistance decreases with an increase in temperature due to increased electron activity caused by temperature.	The insulation resistance decreases with an increase in temperature due to increased electron activity caused by temperature.	The insulation resistance decreases with an increase in temperature due to increased electron activity caused by temperature.	Oxide film in aluminum capacitors will deteriorate and the capacitor may be destroyed upon application of voltage.
	In hermetically sealed capacitors, an increase in temperature will result in an increase in internal pressure which could rupture the hermetic seal and result in increased moisture susceptibility.	In hermetically sealed capacitors, an increase in temperature will result in an increase in internal pressure which could rupture the hermetic seal and result in increased moisture susceptibility.	In hermetically sealed capacitors, an increase in temperature will result in an increase in internal pressure which could rupture the hermetic seal and result in increased moisture susceptibility.	The service life of the capacitor will decrease with an increase in temperature. One of the factors affecting wear out of a capacitor is dielectric degradation resulting from chemical activity with time.

Table 4.1.2.1-1. Environmental Effects/Guidelines for Dormant Fixed Capacitors. (Continued)

Environment	Paper/Plastic	Mica/Glass	Ceramic	Electrolytic
High Temperature (Continued)				The insulation resistance decreases with an increase in temperature due to increased electron activity caused by temperature. In hermetically sealed capacitors, an increase in temperature will result in an increase in internal pressure which could rupture the hermetic seal and result in impregnante leakage and increased moisture susceptibility.
Low Temperature	Capacitance increase of +2% at -55°C.[2]	No effect to -55°C.[2]	Capacitance decrease of -2% at -55°C.[2]	Aluminum capacitance decrease -20% in capacitance at -55°C.[2] Tantalum capacitors decrease -50% in capacitance and may result in open circuits at -55°C.[2]
Humidity (Moisture, Precipitation, Relative Humidity > 90%)	Moisture absorbed by a capacitor can cause parametric changes, reduced service life, and in some cases, early life failures if moisture penetration is	Moisture absorbed by a capacitor can cause parametric changes, reduced service life, and in some cases, early life failures if moisture penetration is	Moisture absorbed by a capacitor can cause parametric changes, reduced service life, and in some cases, early life failures if moisture penetration is	Moisture absorbed by a capacitor can cause parametric changes, reduced service life, and in some cases, early life failures if moisture penetration is

Table 4.1.2.1-1. Environmental Effects/Guidelines for Dormant Fixed Capacitors. (Continued)

Environment	Paper/Plastic	Mica/Glass	Ceramic	Electrolytic
Humidity (Moisture, Precipitation, Relative Humidity > 90%)	significant. The most notable parameters effect is a decrease in insulation resistance.	significant. The most notable parameters effect is a decrease in insulation resistance.	significant. The most notable parameters effect is a decrease in insulation resistance.	significant. The most notable parameters effect is a decrease in insulation resistance.
	If any non-hermetic unit such as the plastic case or plastic wrap-epoxy end-filled style of capacitor, moisture will penetrate and cause significant decreases in insulation resistance.	If any non-hermetic unit such as the plastic case or plastic wrap-epoxy end-filled style of capacitor, moisture will penetrate and cause significant decreases in insulation resistance.	If any non-hermetic unit such as the plastic case or plastic wrap-epoxy end-filled style of capacitor, moisture will penetrate and cause significant decreases in insulation resistance.	If any non-hermetic unit such as the plastic case or plastic wrap-epoxy end-filled style of capacitor, moisture will penetrate and cause significant decreases in insulation resistance.
	Non hermetic designs that use paper dielectrics are more vulnerable to moisture than plastic dielectrics. The paper dielectric will absorb moisture and destroy the dielectric. Paper dielectric capacitors are not recommended for dormant applications in humid environments.	See High Temperature.	Ceramic capacitors are non-hygroscopic, and are as a result the least degraded capacitor in humid dormant applications.	
Solar Radiation	No adverse effects anticipated if temperature does not exceed rated maximum (see High Temperature).	No adverse effects anticipated if temperature does not exceed rated maximum (see High Temperature).	No adverse effects anticipated if temperature does not exceed rated maximum (see High Temperature).	No adverse effects anticipated if temperature does not exceed rated maximum (see High Temperature).

Table 4.1.2.1-1. Environmental Effects/Guidelines for Dormant Fixed Capacitors. (Continued)

Environment	Paper/Plastic	Mica/Glass	Ceramic	Electrolytic
Solar Radiation (Continued)	Possibly fade markings after extended exposure.	Possibly fade markings after extended exposure.	Possibly fade markings after extended exposure.	Possibly fade markings after extended exposure.
	Extended UV radiation could degrade potting and thermo plastic materials with the potential of reducing the seal integrity of the unit.	Extended UV radiation could degrade potting and thermo plastic materials with the potential of reducing the seal integrity of the unit.	Extended UV radiation could degrade potting and thermo plastic materials with the potential of reducing the seal integrity of the unit.	Extended UV radiation could degrade potting and thermo plastic materials with the potential of reducing the seal integrity of the unit.
Low Pressure[1]	Reduced pressure may produce leaks in hermetically sealed units. Possible outgassing of materials. Designer should consult Reference 11 to determine material outgassing.	Reduced pressure may produce leaks in hermetically sealed units. Possible outgassing of materials. Designer should consult Reference 11 to determine material outgassing.	Reduced pressure may produce leaks in hermetically sealed units. Possible outgassing of materials. Designer should consult Reference 11 to determine material outgassing.	Not intended for low pressure applications (see applicable MIL-specifications).
				Reduced pressure may produce leaks in hermetically sealed units. Possible outgassing of materials. Designer should consult Reference 11 to determine material outgassing.
	Capacitance may be affected by internal dimensional changes due to pressure differentials.	Capacitance may be affected by internal dimensional changes due to pressure differentials.	Capacitance may be affected by internal dimensional changes due to pressure differentials.	Capacitance may be affected by internal dimensional changes due to pressure differentials.
	For oil impregnated capacitors, the differential between internal and external pressure becomes greater when the external pressure is reduced. This puts added stress on the seams and ter-			The differential between internal and external pressure could cause leakage in non-

Table 4.1.2.1-1. Environmental Effects/Guidelines for Dormant Fixed Capacitors. (Continued)

Environment	Paper/Plastic	Mica/Glass	Ceramic	Electrolytic
Low Pressure[1]	minal seals and can result in subsequent rupture of the seal and consequent impregnant leakage.			solid electrolytes, and leakage may damage surrounding circuitry.
Wind	No adverse effects anticipated.	No adverse effects anticipated.	No adverse effects anticipated.	No adverse effects anticipated.
Shock	For severe shock and vibration environments, particularly for larger case sizes, supplementary mounting should be used to prevent part failure due to lead fatigue.	No adverse effects anticipated.	Barium titanate has a piezo electric effect, and voltage transients may be generated by shock or vibration. This effect is greater on high K bodies and occurs after the dielectric has been polarized by the application of voltage at of voltage at high temp. It is for this reason that capacitors that have been burned-in exhibit a greater piezo electric effect. Voltages on the order of 150 mV have been measured. Where this effect may be deleterious, a Class I dielectric should be used or the mechanical stress should be isolated.	Possible open circuits resulting from fatigue.

Table 4.1.2.1-1. Environmental Effects/Guidelines for Dormant Fixed Capacitors. (Continued)

Environment	Paper/Plastic	Mica/Glass	Ceramic	Electrolytic
Vibration	Although most QPL vendors are rated for vibrations up to 15 G and 2000 MHz, the capacitor specifications require that the devices be rigidly mounted by the body during qualification tests. For severe vibration requirements, especially for larger case sizes, supplementary mounting means should be used to prevent failure from lead fatigue.	For severe vibration, the case of radial leaded dipped mica styles must be adequately anchored to prevent failure due to lead fatigue.	See Shock	See Shock
Sand & Dust	No adverse effects anticipated.	No adverse effects anticipated.	No adverse effects anticipated.	No adverse effects anticipated.
Salt Fog	Accelerated moisture effects (see Humidity).	Accelerated moisture effects (see Humidity).	Accelerated moisture effects (see Humidity).	Accelerated moisture effects (see Humidity).
Temp Shock	See High Temperature, Low Temperature	See High Temperature, Low Temperature	See High Temperature, Low Temperature	Repeated temperature cycling, will result in electrolyte leakage in non-solid tantalum capacitors. This may not result in severe capacitance deviations, but the corrosive electrolyte leakage will damage surrounding components.

Table 4.1.2.1-1. Environmental Effects/Guidelines for Dormant Fixed Capacitors. (Continued)

Environment	Paper/Plastic	Mica/Glass	Ceramic	Electrolytic
Fungus	Not inherently susceptible to attack by fungus, however, contaminants may provide nutrients for fungus growth.	Not inherently susceptible to attack by fungus, however, contaminants may provide nutrients for fungus growth.	Not inherently susceptible to attack by fungus, however, contaminants may provide nutrients for fungus growth.	Not inherently susceptible to attack by fungus, however, contaminants may provide nutrients for fungus growth.
	Keep humidity below 50%; ideal conditions for fungus growth are 20 - 40°C and 85 - 100% relative humidity.	Keep humidity below 50%; ideal conditions for fungus growth are 20 - 40°C and 85 - 100% relative humidity.	Keep humidity below 50%; ideal conditions for fungus growth are 20 - 40°C and 85 - 100% relative humidity.	Keep humidity below 50%; ideal conditions for fungus growth are 20 - 40°C and 85 - 100% relative humidty.
	Fungus can cause shorts and material deterioration.	Fungus can cause shorts and mateial deterioration.	Fungus can cause shorts and material deterioration.	Fungus can cause shorts and material deterioration.
Acoustic Noise	No adverse effects anticipated.	No adverse effects anticipated.	No adverse effects anticipated.	No adverse effects anticipated.
Gun Fire	See Shock, Vibration	See Shock. Vibration	See Shock, Vibration	See Shock, Vibration
Acceleration	See Shock, Vibration	See Shock, Vibration	See Shock, Vibration	See Shock, Vibration
Space	See Low Pressure, Nuclear Radiation	See Low Pressure, Nuclear Radiation	See Low Pressure, Nuclear Radiation	See Low Pressure, Nuclear Radiation
Electromagnetic Radiation	EMR, primarily lightning, is a more detrimental environment than EMP for dormant equipment, and may be used as a worst case when considering EMP and EMR	EMR, primarily lightning, is a more detrimental environment than EMP for dormant equipment, and may be used as a worst case when considering EMP and EMR	EMR, primarily lightning, is a more detrimental environment than EMP for dormant equipment, and may be used as a worst case when considering EMP and EMR	EMR, primarily lightning, is a more detrimental environment than EMP for dormant equipment, and may be used as a worst case when considering EMP and EMR

Table 4.1.2.1-1. Environmental Effects/Guidelines for Dormant Fixed Capacitors. (Continued)

Environment	Paper/Plastic	Mica/Glass	Ceramic	Electrolytic
Electromagnetic Radiation (Continued)	effects. Generally, EMR has no direct effect on dormant capacitors unless they are close to the surface of dormant equipment that is not completely sealed and grounded. Therefore, EMR effects on dormant capacitors is application, and generally no adverse effects are anticipated.	effects. Generally, EMR has no direct effect on dormant capacitors unless they are close to the surface of dormant equipment that is not completely sealed and grounded. Therefore, EMR effects on dormant capacitors is application, and generally no adverse effects are anticipated.	effects. Generally, EMR has no direct effect on dormant capacitors unless they are close to the surface of dormant equipment that is not completely sealed and grounded. Therefore, EMR effects on dormant capacitors is application, and generally no adverse effects are anticipated.	effects. Generally, EMR has no direct effect on dormant capacitors unless they are close to the surface of dormant equipment that is not completely sealed and grounded. Therefore, EMR effects on dormant capacitors is application, and generally no adverse effects are anticipated.
Electromagnetic Pulse	EMP has no direct effect on dormant capacitors, however, wire runs near the external surfaces of dormant equipment (i.e., cables, antennas, data links, etc.) may be subject to EMP pickup resulting in surge currents. Generally, the surge currents associated with EMP are small due to narrow pulse width. Therefore, the secondary effect on capacitors is application dependent, and no adverse effects are anticipated for dormant equipment. (See EMR)	EMP has no direct effect on dormant capacitors, however, wire runs near the external surfaces of dormant equipment (i.e., cables, antennas, data links, etc.) may be subject to EMP pickup resulting in surge currents. Generally, the surge currents associated with EMP are small due to narrow pulse width. Therefore, the secondary effect on capacitors is application dependent, and no adverse effects are anticipated for dormant equipment. (See EMR)	EMP has no direct effect on dormant capacitors, however, wire runs near the external surfaces of dormant equipment (i.e., cables, antennas, data links, etc.) may be subject to EMP pickup resulting in surge currents. Generally, the surge currents associated with EMP are small due to narrow pulse width. Therefore, the secondary effect on capacitors is application dependent, and no adverse effects are anticipated for dormant equipment. (See EMR)	EMP has no direct effect on dormant capacitors, however, wire runs near the external surfaces of dormant equipment (i.e., cables, antennas, data links, etc.) may be subject to EMP pickup resulting in surge currents. Generally, the surge currents associated with EMP are small due to narrow pulse width. Therefore, the secondary effect on capacitors is application dependent, and no adverse effects are anticipated for dormant equipment. (See EMR)

Table 4.1.2.1-1. Environmental Effects/Guidelines for Dormant Fixed Capacitors. (Continued)

Environment	Paper/Plastic	Mica/Glass	Ceramic	Electrolytic
Nuclear Radiation	Radiation effects experiments have shown that paper and oil impregnated paper capacitors are more sensitive to radiation than the inorganic types (ceramic, mica, and glass by factors of 10^2 to 10^3 (Ref. 16). Hermetically sealed oil impregnated units may rupture from internal pressure increases resulting from radiation (Ref. 16). Paper dielectric capacitors are estimated to permanently deviate as much as -50% to +25% in capacitance in a radiation environment of 10^{12} fast n cm^{-2} sec^{-1} (Ref. 16). Plastic dielectric capacitors are less susceptible to radiation than paper dielectrics but they are still more sensitive than inorganic types by a factor of 10.	Glass capacitors have shown the greatest resistance to radiation induced damage (Ref. 16). Glass dielectric capacitors are estimated to permanently decrease in capacitance less than 1% in a nuclear environment of 10^{15} fast n cm^{-2}. Mica dielectric capacitors are not as stable as glass dielectric capacitors in a nuclear environment. Mica capacitors are estimated to permanently deviate in capacitance between -5% and +5% in a nuclear environment of 10^{15} fast n cm^{-2} sec^{-1} (Ref. 16).	Temperature compensating ceramic dielectric capacitors are estimated to permanently deviate in capacitance less than $\pm 5\%$ in a nuclear environment of 10^{15} fast n cm^{-2} (Ref. 16). General purpose ceramic dielectric capacitors are estimated to permanently deviate between +2% and -20% in a radiation environment of 10^{15} fast n cm^{-2} (Ref. 16).	Information on the results of radiation effects experiments with tantalum and aluminum electrolytic capacitors indicates that both types may be capable of surviving extended exposure to radiation. These results also indicate that tantalum units are more radiation resistant; however they do offer a biological hazard were servicing of equipment may be required. This is due to the activation of the tantalum when subjected to thermal neutrons and the long half life, 111 days, associated with the resulting radioactive species. Tantalum electrolytic capacitors change in capacitance between -2 and -5% in a nuclear environment of 10^{17} fast n cm^{-2}. Aluminum electrolytic capacitors are estimated to permanently decrease in capacitance

Table 4.1.2.1-1. Environmental Effects/Guidelines for Dormant Fixed Capacitors. (Continued)

Environment	Paper/Plastic	Mica/Glass	Ceramic	Electrolytic
Nuclear Radiation (Continued)	Plastic dielectric capacitors are estimated to permenantly increase in capacitance between +5 and +15% in a radiation environment of 10^{11} fast n cm^{-2} sec^{-1} (Ref. 16).			between -5 and -10% in a nuclear environment of 10^{17} fast n cm^{-2}.

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1 Deviations are worst case estimates for dormant equipment. Actual deviations may be less severe; refer to applicable MIL specification. Worst case deviations were provided as recommended design tolerances to insure long term reliability in dormant equipment.

2 As per applicable Military specification ratings.

puncture of the dielectric can cause a relatively harmless vaporization of a small area of the plates (known as "clearings") with the effect of a noise spike and a small reduction of total capacitance. These phenomena are not considered failures of the capacitor, until enough of them occur to cause significant reduction in capacitance. However, metallized plastic capacitors should not be used in timing or memory (storage) circuits or anywhere a momentary breakdown in the dielectric cannot be tolerated. They should not be used in high impedance or low energy circuits where the fault will not clear.

4.1.2.1.2 Fixed Glass and Mica Dielectric Capacitors

These capacitors have non-flexible dielectric materials. To obtain the higher capacitance units, thin layers of the dielectric are stacked between multiple electrodes. Alternate electrodes are connected in parallel. The electrodes can be either metallic foil or a metallic film painted directly on the dielectric. The assembled stack of electrodes and dielectrics is held in close contact by clamps or by the capacitor encasement.

Mica is one of the very few natural materials directly adaptable for use as a capacitor dielectric. Its physical properties, plus its rare characteristics of nearly perfect cleavage make it probably the best known capacitor dielectric. It is inherently stable, both dimensionally and electrically, therefore, mica capacitors exhibit excellent temperature coefficient characteristics and very low aging with operation.

Glass dielectric capacitor electrical characteristics are very similar to those of mica capacitors: they have excellent long term stability, a low temperature coefficient and a history of good reliability.

4.1.2.1.3 Fixed Ceramic Dielectric Capacitors

These capacitors are available either as tubular, flat disc, or flat plate designs. Tubular designs consist of a ceramic type with silver bands (electrodes) fired on the inside and outside surfaces. Capacitance is formed between the silver bands with the ceramic as the dielectric. Leads are wrapped around each end soldered to the bands, and exit radially from the tube and are parallel. The assembly is encapsulated in resin which is subsequently vacuum-impregnated with a high melting point wax.

Disc designs consist of a disc with a thin coating of metallic paint fired on each face. Parallel leads are soldered to the metallic electrodes. The assembly is encapsulated in resin and impregnated with a high melting point wax.

Flat plate capacitors consist of a monolithic stack in a molded case. The internal stack consists of multiple films of a noble metal spaced with thin films of ceramic. This assembly is fired to give a monolithic construction.

In dormant applications, capacitors with wax impregnated conformal coating will collect dust and other contaminants. Under these conditions, the insulation resistance will decrease under prolonged high humidity conditions.

During dormancy, excessive moisture should be avoided since the encapsulation material may absorb moisture and silver ion migration may occur when the capacitors are later put into service. Silver ion migration can cause short circuits in short periods of time in humid conditions.

4.1.2.1.4 Fixed Electrolytic Dielectric Capacitors

There are two types of electrolytic capacitors: aluminum and tantalum. Tantalum electrolytic capacitors are be further subdivided as solid or non-solid dielectric types. Non-solid tantalums are further divided into foil and sintered slug types. The construction of each of these types is summarized below:

Aluminum Electrolytic Capacitors

Aluminum electrolytic capacitors consist of an aluminum foil rolled unto a porous spacer. The spacer is impregnated with an electrolyte and separates the anode and cathode. The electrolyte is usually an aqueous solution of ammonium borate, boric acid, and glycol.

Solid Tantalum Dielectric Electrolytic Capacitors

Solid tantalum dielectric electrolytic capacitors consist of a porous tantalum pellet or wire which serves as the anode or electrode. The surfaces of the anode are electrochemically converted to an oxide of tantalum which serves as the dielectric. These surfaces are coated with an oxide semiconductor which is the working electrolyte in solid form. This oxide semiconductor establishes contact with all of the complex surfaces of the anodized pellet and is capable of healing imperfections of the tantalum oxide dielectric film.

Solid tantalum chip capacitors consist of a porous tantalum slab which serves as the anode. The surfaces of the anode are electrochemically treated to form a tantalum oxide dielectric. These surfaces are coated with an oxide semiconductor which is the working electrolyte in solid form.

Non-Solid Tantalum Dielectric Electrolytic Capacitors

Non-solid foil types consist of a tantalum foil, as the anode. This anode is electrochemically treated to form a layer of tantalum oxide dielectric. Porous spacer material is used to form a conventional cylindrical capacitor section with axial tantalum wires on either end. The section is impregnated with a suitable electrolyte (usually a weak acid or base) and then sealed in a suitable container. Solderable leads are welded to the tantalum leads.

Sintered-slug types consist of a sintered slug of a tantalum as the anode. This anode is electrochemically treated to form a layer of tantalum oxide. Porous spacer material is impregnated with a suitable electrolyte and then sealed in a suitable container.

Electrolytic capacitors have experienced problems in storage. Table 4.1.2.1.4-1 summarizes the predominant failure mechanisms associated with solid tantalum types. Table 4.1.2.1.4-2 summarizes those for wet tantalum types. Electrolyte leakage in wet tantalum capacitors has been the major source of problems, while impurities in solid types has been one of the predominant problems. Most of the failure mechanisms associated with these capacitors are accelerated to failure by a temperature cycling environment. (Ref 18)

Aluminum electrolytic capacitors experience deterioration of the oxide film when placed in a dormant mode. The oxide film deforms at noor low-voltage and the capacitor is destroyed by application of full rated voltage. These devices are not recommended for dormant application, however, if these devices are used in dormant equipment, MIL-STD-1131B (Ref 25) Presents guidelines for the storage, inspection, and reformation of these devices. If aluminum electrolytic capacitors have been in storage for longer than 5 years, it is recommended that the capacitors be checked for leakage.

Although electrolytic capacitors are the most volumetric and cost efficient, they are not recommended for dormant applications without application of the following guidelines to insure long life reliability in dormant applications. (Ref 24)

- Use only hermetically sealed capacitors to provide maximum stability and reliability, and prevent outgassing during low pressure operations.

Table 4.1.2.1.4-1. Failure Mechanism Analysis, Solid Tantalum Capacitors (Ref. 18).

Failure Mechanism	Cause	Accelerating Environment	Failure Mode	Detection Method
Oxide Defects	Impurities in starting tantalum impede oxide growth at sites during anodization.	Temperature cycling, burn in	Out-of-tolerance	High leakage currents, or outliers
	Abrasions of sintered pellets expose impurities prior to anodization.			
	Bincer or die impurities on sintered pellet.			
	Handling damage during anodization processes and assembly.			
	Crystalline tantalum pentoxide.			
	Oxide shorts due to excessive power surges under flicker or scintillation conditions.	Surge Test	Short	Short circuits
	Thin MnO_2 or silver paint penetrating MnO_2 and preventing healing of defect sites.	Temperature cycling, burn in, surge test	Out-of-tolerance	High leakage currents, or outliers. High dissipation factor.
Poor Slug Adhesion	Inadequate wetting of solder to silver paint.	Temperature cycling, burn in	Out-of-tolerance	Dissipating, capacitance radiographic inspection
	Silver paint dissolving into the solder.			
	Low solder level, poor anchorage of slug to case, flux between solder and paint.	Temperature cycling, burn in		Radiographic inspection
Solder Reflow	Excessive heat applied during assembly of capacitor into circuit.			Radiographic inspection
Mechanical Defects	Solder distributions, voids, slugs canted in case, bent risers, etc.			Radiographic inspection

Table 4.1.2.1.4-2. Failure Mechanism Analysis, Non-Solid Tantalum Capacitors (Ref. 18).

Failure Mechanism	Cause	Accelerating Environment	Failure Mode	Detection Method
Electrolyte Leakage	Leakage past center of seal causing electrolyte to bridge between internal nickel wire and case.	Temperature cycling, burn in	Shorts, open, capacitance, leakage	Visual inspection, electrical test
Insulation Defects	Metallic contamination in mylar sleeving, improperly cured epoxy compound.	Temperature cycling, burn in	Short, dissipation factor	Electrical test
Foil Separation	Reactive impurities in electrolyte or in paper spacer.	Temperature cycling, burn in	Capacitance, dissipation factor	Electrical test
Faulty Lead to Foil Welds	Machine and operator errors cause inadequate welds	Temperature cycling, burn in	Open	Visual, electrical test

- Solid tantalum electrolyte capacitors exhibit excellent storage life characteristics, however these capacitors should be applied with a limiting series resistance of 3 ohms per volt minimum to avoid potentially catastrophic breakdown.

- For foil and wet slug capacitors, the leads should be welded to anodized tantalum risers external to the hermetic seal so as to provide a completely insulated structure within the seal.

- The tantalum riser wires should not extend more than 1/4 inch beyond the seal to minimize the possibility of bending and therefore damaging the riser and its oxide, particularly at the seal area.

- The cathode lead of wet slug capacitors in silver cans should be of a material which is weldable to silver without causing crystallization or punch-through. For this purpose, silver or oxygen free copper is superior to other material such as nickel.

- Gelled electrolyte is preferred over liquid sulfuric acid electrolyte in wet slug capacitors because of lesser mobility.

- The proper high temperature solder must be used in fabrication to prevent reflow during assembly operations.

- The attachment of slugs into solid electrolyte capacitor cases must utilize silver bearing solder to prevent silver paint dissolving into the solder.

- Plain foil capacitors are preferred over the etched foil, since the etched foil is somewhat more prone to manufacturing process errors.

- Seal test should be performed on 100% of the devices to verify every seal. In addition, if acid electrolyte is used a litmus paper or thymol blue test should be added to the usual leak test.

- When capacitors are used in banks, they should be assembled in easily removable modules to facilitate replacement and test.

- The largest possible case size should be used for a given capacitor voltage rating as this provides thicker oxide dielectric, lower ESR, lower dissipation factor, better heat dissipation, and greater capacitance stability.

- For long life high reliability usage, the Peak voltage including surges and transients should be limited to 50% of the manufacturer's derated ratings for all tantalum capacitors.

- For foil and solid electrolyte capacitors, the allowable ripple current should be derated to 70% of the manufacturer's derated rating for high reliability.

- The temperature of solid electrolyte capacitors should be limited to 50 deg C including internal temperature rise. For long life, the foil and wet slug types should be held to 70 degrees.

4.1.2.2 General Characteristics of Variable Capacitors

Generally, variable capacitors are highly unstable devices, and they are not recommended for dormant applications. Tolerances of variable capacitors reflect their instability. Periodic inspection is required to insure that variable capacitors are maintained within their capacitance values. This will impact the maintenance concept selected for the dormant equipment. Refer to section 4.3 (Maintainability Design) of this text for a more detailed discussion of maintainability design guidelines for dormant equipment.

Environmental degradation is a significant failure mode for variable capacitors. Variable capacitors are highly susceptible to moisture, temperature, shock, vibration, and contaminant induced failures. Variable capacitors cannot be sealed in a complete encapsulated jacket.

Variable capacitors have movable shafts which protrude through the case and possibly through the front panel of equipment. This opens the interior of the variable capacitor and possibly the interior of equipment to the environment exterior. Various types of shaft seals. such as elastomer '0' rings can be used to protect the capacitor interior, but they are imperfect seals.

Dormant variable capacitors should not be lubricated with a liquid lubricant, because the presence of oil lubricants can collect dust and other potentially corrosive and degradative contaminants.

When the use of variable capacitors is required, they should be maintained in an enclosed unit to Protect the interior of the capacitor mechanisms from degrading environmental influences.

The use of variable capacitors in dormant applications should be avoided, however when a variable capacitor is necessary, air trimmers should be used because they offer the highest degree of stability of variable capacitor types.

4.1.2.2.1 Variable Ceramic Dielectric Capacitors

These variable capacitors consist of a single stator and a single rotor for each section, made of ceramic material impregnated with transformer or silicone oil. Pure silver is fired and burnished on the top of the base of the stator in a half moon-pattern. The rotor, usually of titanium dioxide, has pure silver contact points. The contact surfaces of both the stator and the rotor are ground and lapped flat, thus eliminating air space variations with temperature.

These capacitors are unstable with temperature changes and at high and low temperature ratings. Changes in capacitance from the nominal value measured at 25 degrees C may vary from -4.5 to .14% at -55 degrees C or -10 to .2% at +85 degrees C. Temperature sensitivity in these units is nonlinear over the capacitance range and varies greatly between the units. These capacitors should not be designed into circuits as temperature compensating units.

4.1.2.2.2 Variable Capacitors Tubular Type

These capacitors are constructed of a series of concentric circular metal bands with inter leaf and are variable by adjustment of the related depth of the interface. All other style capacitors are constructed of glass, quartz, sapphire, or alumina dielectric cylinders and metal tuning pistons. A portion of the cylinder is plated with metal to form the stator and the metal piston, controlled by a tuning screw, acts as the rotor for these variable capacitors. The overlap of the stator and the rotor determines the capacitance.

4.1.2.2.3 Air Dielectric Capacitors

Air dielectric capacitors consist of multiple rotors and stators, each having a half moon shape. The overlap of rotors an stators determine the capacitance. The rotors can be rotated continuously and full capacitance change occurs during each 360 degree rotation.

4.1.3 Microcircuits

Microcircuit devices are broadly classified by the way in which they are packaged (hermetic vs. non-hermetic) and by the type of testing and screening they are subjected to during processing. The screening specifications for microcircuits determines the quality level to which the devices are classified. For military and aerospace applications, the highest quality, most thoroughly screened microcircuits are packaged in hermetic packages and are procured per MIL-M-3S510. This specification establishes the design, inspection, testing, and their reliability assurance requirements for monolithic, multichip, and hybrid microcircuits.

Microcircuits are precision composite structures composed of materials which have been chosen to provide desired electronic functions. Their small geometries and the intricate nature of the composite materials employed make detailed chemical and geometrical stability highly critical to device reliability and performance. Conditions which alter the intended physical arrangement of materials in minute detail can have catastroghic consequences on device performance.

It is generally true that the materials employed in most microcircuit structures will change very slowly when protected from degrading environmental factors. Properly fabricated microcircuits might well remain stable for decades if stored in a perfectly dry environment at a low and constant temperature. (Ref. 3) Unfortunately, these conditions are seldom achieved for most military electronic equipment. Table 4.1.3-1 summarizes.the effects of various environmental factors microcircuits during non-operating periods.

In his study of the failure mechanisms and materials degradation process which will cause the failure of microcircuits during long-term non-operating periods (Ref. 3), Livesay concluded that the most important environmental stresses during non-operating periods are mechanical, chemical, and low thermal. Mechanical stresses occur due to thermal mechanical interactions and residual stresses resulting from device fabrication and processing. Chemical stresses result form contaminants such as residual process chemicals and environmental gases which are introduced through improper or failed seals in hermetic packages. Although purely thermal stresses are much less important during non-operating periods as compared with operating conditions, certain low temperature reaction rates and diffusion processes are temperature dependent and will proceed at reduced rates over the non-operating temperature range. Of critical importance is the synergism of the three primary non-operating stresses. While any one of the three acting alone may not have a deleterious effect, the combined effect of two or three working together can cause device failures.

The failure mechanisms of greatest importance during non-operating periods are those related to manufacturing defects, corrosion processes, and mechanical fracture. Since a non-operating environment is normally free of electrical stresses, electrical and potential current induced degradation processes are not important in the nonoperating environment except when the environment itself provides the electrical stresses (e.g. See EMP effects in Table 4.1.3-1).

Although the operating and non-operating environments for microcircuits may be quite different, experience (Refs. 5-10) has shown that most failures that occur during dormancy are of the same basic kind as those found in the operating mode and are the result of the further

Table 4.1.3-1. Environmental Effects/Guidelines for Dormant Microcircuits.

	Hermetic		Non-Hermetic	
Environment	Monolithic	Hybrid	Plastic Encapsulated	Polymer Sealed
High Temperature	1. The maximum high non-operating temperature is typically +150°C. 2. Will accelerate failures due to latent defects such as bulk defects (dislocation and stacking faults, impurity diffusions and precipitations, cracks), improper diffusions or doping profile, oxide defects, metallization defects, cracks, or voids between header and die, wire bonding defects, contamination (including moisture) and final seal defects. 3. Will accelerate time-dependent formations of intermetallic compounds at metal-metal contacts such as gold-aluminum, silver-copper, etc. 4. Unmounted components may experience lead finish oxidation. Generally corrected by cleaning before soldering. 5. The use of gold-aluminum bonds in a high temperature environment should be avoided.	1. The maximum high non-operating temperature is dependent upon the devices making up the hybrid device but is typically in the range of 125°C to +150°C. 2. See Monolithic High Temp. Items 2, 3, 4, and 5. 3. Will accelerate leaching or diffusion of film resistors at resistor-conductor interface. 4. Discrete components may experience parameter drifts (see applicable discrete component section for details).	1. The maximum high non-operating temperature for monolithic devices is dependent upon the encapsulating (sealing) material but is typically +150°C. 2. See Monolithic High Temp. Items 2, 3, 4, and 5. 3. For Hybrid devices, see Hybrid High Temp. Items 1, 3, and 4. 4. Maximum Temperature should be kept below the glass transition temperature of the encapsulating (sealing) material.	See Plastic Encapsulated High Temp.

Table 4.1.3-1. Environmental Effects/Guidelines for Dormant Microcircuits. (Continued)

Environment	Hermetic: Monolithic	Hermetic: Hybrid	Non-Hermetic: Plastic Encapsulated	Non-Hermetic: Polymer Sealed
Low Temperature	1. The minimum low non-operating temperature is typically -65°C. 2. Will generally decelerate temperature dependent failure mechanisms. 3. Moisture entrapped during processing or resulting from a seal leak will condense on device surfaces if the temperature drops to the dew point. A dew point of -65°C corresponds to a moisture content of approximately 5 ppm by volume. (Ref. 3) 4. Stresses induced by thermal expansion coefficient differences may excite defects in materials such as cracks, voids, and bulk defects resulting in mechanical fracture failure mechanisms, open bonds, etc.	1. The minimum low non-operating temperature is dependent upon the devices making up the hybrid device but is typically in the range of -55°C to -65°C. 2. See Monolithic Low Temp. Items 2, 3, and 4. 3. Discrete components may experience parameter drifts (see applicable discrete component section for details).	1. The minimum low non-operating temperature is dependent upon the encapsulating (sealing) material but is typically -65°C. 2. See Monolithic Low Temp. Items 2, 3, and 4. 3. See Hyprid Low Temperature Items 1 and 3. 4. Non-hermetic devices do not provide protection from ambient moisture. The dew point will therefore vary with the moisture content of the ambient atmosphere and will be considerably above -65°C.	See Plastic Encapsulated Low Temp.
Humidity (Including Moisture, Precipitation)	1. Extremely low humidity is ideal (< 10% relative humidity).	See Monolithic Humidity.	1. Non-hermetic devices provide no protection from ambient atmospheric moisture and are not recommended for equipment that	See Plastic Encapsulated Humidity.

Table 4.1.3-1. Environmental Effects/Guidelines for Dormant Microcircuits. (Continued)

Environment	Hermetic: Monolithic	Hermetic: Hybrid	Non-Hermetic: Plastic Encapsulated	Non-Hermetic: Polymer Sealed
Humidity (Including Moisture, Precipitation) (Continued)	2. Moisture within a device package induces corrosion process directly and activates contaminants such as residual chlorine ions. It may be the single most important factor to long-term non-operating reliability and all steps should be taken to eliminate it. The amount of moisture required to degrade materials within a device may be as little as one molecular layer. (Ref. 3) 3. Hermetically sealed devices provide the best protection against ambient atmospheric moisture and should be used in equipment that will be dormant for long periods of time.		will be dormant for long periods of time. (See Monolithic Humidity Items 1 & 2) 2. All plastics contain moisture to some degree (see Figure 4.1.3.2.1-1). Moisture also enters plastic encapsulated devices along imperfect plastic/lead bonds because little or no chemical bonding takes place. 3. Passivation coatings such as silicon dioxide and silicon nitride can provide some protection from moisture and contaminants but they have not, by themselves, been proven as effective as hermetically sealed devices. 4. Devices fabricated with trimetal metallization and epoxy novolac encapsulant have demonstrated storage reliability comparable to ceramic DIPs in tests conducted in Panama. (Ref. 32) 5. If non-hermetic devices are to be used in long-term dormant applications they must be pro-	2. Polymer seals deteriorate badly in moist environments. During tests they have deteriorated so badly that device lids fell off through handling and testing. (Ref. 34)

Table 4.1.3-1. Environmental Effects/Guidelines for Dormant Microcircuits. (Continued)

	Hermetic		Non-Hermetic	
Environment	Monolithic	Hybrid	Plastic Encapsulated	Polymer Sealed
Humidity (Including Moisture, Precipitation) (Continued)			tected from ambient atmospheric moisture through atmospheric control or hermetic sealing of the equipment in which they are used.	
Solar Radiation	1. No effect anticipated if absorbed radiation results in temperature below maximum. (See High Temperature) 2. Possibly fade markings after extended exposure.	See Monolithic Solar Radiation.	1. See Monolithic Solar Radiation. 2. Extended UV radiation could degrade encapsulating (sealing) materials reducing mechanical integrity.	See Plastic Encapsulated Solar Radiation.
Low Pressure	1. The differential between the internal and external pressure is increased. This puts added stress on seams and terminal seals and can result in subsequent rupture of the hermetic seal. 2. Some materials will outgas at low pressures. The designer should consult Reference 11 to identify outgassing effects for low pressure applications.	See Monolithic Low Pressure	See Monolithic Low Pressure.	See Monolithic Low Pressure.

Table 4.1.3-1. Environmental Effects/Guidelines for Dormant Microcircuits. (Continued)

	Hermetic		Non-Hermetic	
Environment	Monolithic	Hybrid	Plastic Encapsulated	Polymer Sealed
Low Pressure (Continued)	3. Avoid the use of any devices constructed with polymers made with catalysts. The catalysts catalyze decomposition of the polymer in a low pressure environment unless thoroughly removed. 4. Avoid the use of devices constructed with polymers made with platicizers and mold lubricants. The presence of residual amounts of these substances is highly detrimental to polymer stability in a vacuum.			
Wind	No data available, no adverse effects anticipated.	See Monolithic Wind.	See Monolithic Wind.	See Monolithic Wind.
Shock	1. No adverse effects within MIL-SPEC limits. 2. Will accelerate failure due to latent defects such as cracks in bulk materials, dislocation and stacking faults, resistivity gradients, voids and cracks between header and die, defective bonds, overbonding, wire defects, unremoved	See Monolithic Shock.	1. See Monolithic Shock Items 1 and 3. 2. Mechanical shock will accelerate failure due to latent defects such as cracks in bulk material, dislocation and stacking faults, resistivity gradients, and voids under metallization.	See Monolithic Shock.

Table 4.1.3-1. Environmental Effects/Guidelines for Dormant Microcircuits. (Continued)

	Hermetic		Non-Hermetic	
Environment	Monolithic	Hybrid	Plastic Encapsulated	Polymer Sealed
Shock (Continued)	pigtails, defective hermetic seals, failure due to conductive particles in package cavity. 3. Mechanical shock during non-operating periods is primarily the result of transportation and handling. Except for large hybrids, most microcircuits have very small masses and are not particularly susceptible to damage from shock induced during transportation and handling.		3. Plastic Encapsulated devices are less susceptible to shock then hermetic devices because the entire device is encased in plastic. In addition, because the encapsulating material is in direct contact with the chip, failures due to loose conductive particles are eliminated.	
Vibration	1. No adverse effects within MIL-SPEC limits. 2. Vibration will accelerate the same latent defects described in Monolithic Shock Item 2, especially at resonant frequencies. 3. Vibration during non-operating periods is primarily the result of transportation and handling. Except for large hybrids, most micro circuits	See Monolithic Vibration.	1. See Monolithic Vibration Items 1 and 3. 2. Vibration will accelerate failure due to latent defects such as cracks in bulk material, dislocation and stacking faults, resistivity gradients, and voids under metallization. 3. Plastic encapsulated devices are less susceptible to vibration than hermetic devices because the entire device is en-	See Monolithic Vibration.

Table 4.1.3-1. Environmental Effects/Guidelines for Dormant Microcircuits. (Continued)

	Hermetic		Non-Hermetic	
Environment	Monolithic	Hybrid	Plastic Encapsulated	Polymer Sealed
Vibration (Continued)	have very small masses and are not particularly susceptible to damage from vibration induced during transportation and handling.		cased in plastic. In addition, because the encapsulating material is in direct contact with the chip, failures due to loose conductive particles are eliminated.	
Sand and Dust	Can cause moisture traps, and introduce contaminants which will accelerate corrosive effects.	See Monolithic Sand and Dust.	See Monolithic Sand and Dust.	See Monolithic Sand and Dust.
Salt Fog	1. Accelerated moisture effects (see Monolithic Humidity Item 2).	1. Accelerated moisture effects (see Monolithic Humidity Item 2).	1. Accelerated moisture effects (see Monolithic Humidity Item 2).	1. Accelerated moisture effects (see Monolithic Humidity Item 2).
	2. Passivate devices with silicon nitride to act as a diffusion barrier for mobile alkali ions.	2. See Monolithic Salt Fog Items 2, 3, and 4.	2. See Monolithic Salt Fog Items 2 and 4.	2. See Monolithic Salt For Item 2 and 4.
	3. Will cause sever corrosion/contamination problems if hermetic seal is defective.		3. Will cause severe corrosion/contamination problems if transported through encapsulating material or along lead seal.	3. Will cause severe corrosion/contamination problems if transported through seal.
	4. May cause lead corrosion.			
Temperature Shock/ Thermal Cycling	1. Differences in thermal expansion coefficient of materials in contact will cause	1. See Monolithic Temp. Shock/ Thermal Cycling.	1. See Monolithic Temp. Shock/ Thermal Cycling.	1. See Monolithic Temp. Shock/Thermal Cycling.

Table 4.1.3-1. Environmental Effects/Guidelines for Dormant Microcircuits. (Continued)

	Hermetic		Non-Hermetic	
Environment	Monolithic	Hybrid	Plastic Encapsulated	Polymer Sealed
Temperature Shock/ Thermal Cycling (Continued)	thermal/mechanical stresses which will accelerate latent manufacturing defects such as cracks in bulk material, cracks in oxide, improper diffusions or doping profile, pinholes, surface metallization flaws, insufficient metallization at oxide steps, voids under metallization, defective bonds, defective hermetic seals, conductive particles in package. 2. Thermal shock is most critical for materials having high thermal impedance such as ceramics.	2. Discrete components may experience parameter drifts (see applicable discrete component section for details).	2. Because plastic encapsulated devices are completely encased in plastic, failures due to conductive particles in the package are not a problem. However, thermal mismatches between the encapsulating material and the device materials may make encapsulated devices more susceptible to failure due to temp. shock/ thermal cycling. 3. Because they are not hermetically sealed, non-hermetic devices may be more susceptible to moisture related failures due to a moisture breathing effect during thermal cycling.	2. See Plastic Encapsulated Temp. Shock/Thermal Cycling Item 3.
Fungus	1. Not inherently susceptible to attack by fungus, however, contaminants may provide nutrients for fungus growth. 2. Keep humidity below 50%; ideal conditions for fungus growth are 20 - 40°C and 85 - 100% relative humidity. 3. Fungus can cause shorts and material deterioration.	See Monolithic Fungus.	1. See Monolithic Fungus. 2. Improperly cured polymers may provide nutrients for fungus growth.	See Plastic Encapsulated Fungus.

Table 4.1.3-1. Environmental Effects/Guidelines for Dormant Microcircuits. (Continued)

	Hermetic		Non-Hermetic	
Environment	Monolithic	Hybrid	Plastic Encapsulated	Polymer Sealed
Acoustic Noise	No data available, no adverse effects anticipated.	No data available, no adverse effects anticipated.	No data available, no adverse effects anticipated.	No data available, no adverse effects anticipated.
Gun Fire	Severe shock, vibration, and acceleration. (See Shock and Vibration)	Severe shock, vibration, and acceleration. (See Shock and Vibration)	Severe shock, vibration, and acceleration. (See Shock and Vibration)	Severe shock, vibration, and acceleration. (See Shock and Vibration)
Acceleration	See Shock, Vibration.	See Shock, Vibration	See Shock, Vibration.	See Shock, Vibration.
Space	See Low Pressure, Nuclear Radiation.	See Low Pressure, Nuclear Radiation.	See Low Pressure, Nuclear Radiation.	See Low Pressure, Nuclear Radiation.
Electromagnetic Radiation (EMR) (Including Electrostatic Discharge)	1. Many circuits, especially MOS and VLSI/VHSIC devices, are susceptible to damage due to static electricity and must be handled in accordance with DOD-STD-1686 and DOD-HDBK-263 to avoid damage. 2. When installed in equipment microcircuits are susceptible to damage from voltage transients as a result of static discharge or ambient EMR such as lightning unless transient protection is provided. Use in line filter and shielding (gasket materials) to attenuate the effects of EMR.	See Monolithic Electromagnetic Radiation.	See Monolithic Electromagnetic Radiation.	See Monolithic Elecmagnetic Radiation.

Table 4.1.3-1. Environmental Effects/Guidelines for Dormant Microcircuits. (Continued)

	Hermetic		Non-Hermetic	
Environment	Monolithic	Hybrid	Plastic Encapsulated	Polymer Sealed
Electromagnetic Pulse (EMP)	Emp is the result of high altitude nuclear blasts. Wire runs near the external surfaces of dormant equipment (i.e., cables, antennas, data links, etc.) may be subject to EMP pickup resulting in voltage and current transients which can damage microcircuits in a manner similar to EMR. (See EMR)	See Monolithic EMP.	See Monolithic EMP.	See Monolithic EMP.
Nuclear Radiation	The effects of GAMMA Rays and XRAYS on non-biased devices is negligible. Neutrons, however, damage the lattice structure of the device under any bias condition and will result in degraded performance or failure of the device. Typical neutron radiation effects are noted in Note 1. In addition to these effects, the physical properties of any polymers used in the construction of the device will be affected by ionizing radiation such as Gamma rays, Xrays, and neutrons. This may lead to a loss of structural integrity and	See Monolithic Nuclear Radiation.	See Monolithic Nuclear Radiation.	See Monolithic Nuclear Radiation.

Table 4.1.3-1. Environmental Effects/Guidelines for Dormant Microcircuits. (Continued)

Environment	Hermetic: Monolithic	Hermetic: Hybrid	Non-Hermetic: Plastic Encapsulated	Non-Hermetic: Polymer Sealed
Nuclear Radiation (Continued)	device failure. For a more detailed discussion of the effects of nuclear radiation on devices the reader should refer to references 16, 43, 44, and 45.			

Note 1: Effects of neutron radiation on dormant microcircuits and discrete semiconductors:

Part Type	Neutron Effect	Design Impact
Diode (Switching, Rectifying)	Change in V_F and I_R	Negligible below 1×10^{13} neutrons/cm^2
Zener and Reference Diodes	Change in V_Z	Negligible below 1×10^{13} neutrons/cm^2
Bipolar Transistors	Decrease in h_{FE}, change in $V_{CE(SAT)}$ I_{CBO}, and I_{EBO}	h_{FE} degradation is dominant. Negligible below 1×10^{13} neutrons/cm^2
SCR	Change in V_{GT} and I_{GT}	Negligible below 1×10^{11} neutrons/cm^2
Bipolar Digital Microcircuits	Failure	Negligible below 5×10^{13} neutrons/cm^2
Bipolar Linear Microcircuits	Change in V_{OS}, I_{OS}, I_b, slew rates, etc.	Minimal below 1×10^{12} neutrons/cm^2
JFET	Change in I_{GSS}	Minimal below 1×10^{13} neutrons/cm^2
MOS	Change in V_{TH}, I_{DDS}, V_{on} I_{LEAK}	Negligible below 1×10^{14} neutrons/cm^2

degradation of latent manufacturing defects which are not detected during device screening. Even the corrosion and mechanical fracture failure mechanisms can usually be traced to a latent manufacturing defect.

The overwhelming area of concern for long-term non-operating reliability of microcircuit devices is the influence of chemical contaminants introduced either from the environment of else during fabrication. As stated in section 4.1, moisture, in particular, is very critical because of the corrosion processes it induces directly and because the presence of moisture activates such contaminants as residual chlorine ions. It may be the single most important factor to long-term non-operating reliability of microelectronic devices. Because the amount of water required to degrade the materials within a device package is very small, as little as one molecular layer according to some sources (Refs. 3,4), all possible steps should be taken to eliminate it within microelectronic devices. The use of hermetically sealed devices, therefore, is highly recommended. Plastic encapsulated devices are non-hermetic and, as a general rule, should not be used for dormant designs.

The following sections provide further details to assist in the selection of microcircuit devices for equipment that will spend a significant part of its service life in a non-operating state. Sections 4.1.3.1 and 4.1.3.2 cover hermetic and non-hermetic microcircuits respectively. Section 4.1.3.3 covers the application of VHSIC/VLSI technology. Finally, microcircuit stress screening is described in section 4.1.3.4.

4.1.3.1 Characteristics of Hermetic Microcircuits

The primary concern for long-term non-operating reliability is the sensitivity of electronic components, bonds, metallization, etc. to the presence of water vapor in the device package. Sources of water vapor include the sealed-in atmosphere, epoxies used for die attachment, polymer conformal coatings, leakage through polymer seals. leakage through minimal leaks for devices that Pass the screen tests, and leakage due to seal failures resulting from the operating and non-operating environments (e.g. thermal cycling).

In an effort to protect microcircuit devices from the effects of ambient atmospheric moisture and other contaminants, microcircuit devices are encapsulated in glass, ceramic, or metal hermetic packages. While hermeticity implies a perfect package such that the electronic devices are protected from the detrimental effects of atmospheric constituents, a perfect hermetic seal with a zero leak rate is impossible to achieve.

Accepting a finite leak rate implies that there will be a gaseous exchange process taking place during non-operating periods until atmospheric equilibrium is reached. The time it takes to reach equilibrium is dependent upon the leak rate. For example, a 1 cm^3 package with a leak rate of $5x10^{-6}$ atm cm^3 sec^{-1} will reach equilibrium with the atmosphere within days. (Ref. 3) Such a leak rate is intolerable for long-term non-operating microcircuits in an uncontrolled, humid environment. The consequences of moisture within a microcircuit package are a number of failure mechanisms including corrosion, ionic drift, reactions with phosphorous-doped passivation glasses, and the formation of migrated gold resistive shorts.

Even if the hermetic seal is perfect (i.e. zero leak rate), moisture may still be present within the device package as a result of entrapped water vapor during sealing or the outgassing of water vapor from the materials enclosed within the device package (e.g. epoxies, polymer conformal coats, etc.). To minimize the amount of moisture introduced during fabrication, Livesay (Ref. 3) recommends that all hermetically packaged microcircuits be vacuum baked at 150 degrees C for at least 4 hours and sealed in dry nitrogen without ever being exposed to moisture containing gases such as air. The moisture content of the nitrogen sealing chamber must also be less than 100 ppm.

For a more detailed discussion of hermeticity and the impact of moisture on microcircuit device reliability, the interested reader is referred to reference 3. The following sections provide additional part selection information concerning hermetic monolithic microcircuits (Section 4.1.3.1.1) and hermetic hybrid microcircuits (Section 4.1.3.1.2).

4.1.3.1.1 Hermetic Monolithic Microcircuits

Monolithic refers to a device fabricated on a single chip of semiconductor material. The two primary technologies for device construction are bipolar and MOS (metal oxide semiconductor). The term bipolar refers to the fact that carriers of both polarities, + (holes) and - (electrons), are necessary for device operation. In contrast, MOS devices are unipolar since only one type of carrier is used. For P channel MOS, the carriers are holes. For N channel MOS, the carriers are electrons.

Another distinction arises from the differing location of active regions. Bipolar devices are considered "bulk" devices because the active region, the base, is located several microns beneath the surface between the emitter and collector. MOS devices, on the other hand, are "surface effect" devices because the active region consists of a channel that is induced at the silicon/silicon dioxide interface. This makes MOS device more sensitive to surface contamination than bipolar devices.

References 18 and 26 break down device construction into seven major areas: Bulk materiel and diffusion, oxide, metallization, glassivation, die bonding, chip connections, and Packaging characteristics. For a more detailed discussion of each of these construction areas the reader should refer to these references.

The failure mechanisms affecting semiconductors are generally the same regardless of the device type. They are also the same regardless of whether the device is in an operating or dormant state. The difference is the frequency at which individual failure mechanisms occur. In general, the mechanisms can be grouped into three categories (Ref. 18):

1. Mechanisms for which failure occurrence is independent of the application environment.

2. Mechanisms for which failure occurrence is dependent on the application environment.

3. Mechanisms for which the failure occurrence is time-related and environment dependent.

The mechanisms in group 1 are undetected defects, such as improper diffusions, oxide pinholes, etc., which passed through device screening. The rate of occurrence of these mechanisms is the same regardless of whether the device is applied in an operating or non-operating environment. The only difference is the time at which the defect is detected.

The mechanisms in group 2 are defects which do not fail the device immediately but require an environmental factor to trigger the failure. Examples of such defects are bond and metallization defects which progress to failure as a result of temperature or mechanical stresses.

The mechanisms in group 3 are similar to group 2 except that they are more time dependent. Examples of such defects are metal migration, intermetallic compound formations, corrosion, etc.

Since the mechanisms in groups 2 and 3 are dependent upon the environment, they will occur at different rates depending upon whether the device is operating or dormant. In most cases the non-operating environment will be more benign than the operating environment and the rate of occurrence of these mechanisms will be much lower.

In considering operating and non-operating failure rates, the complexity of the device is also important. A greater number of circuits in a given die area increases the temperature to which the devices are subjected and also requires greater process control in production. Diffusions, metallization patterns, and interconnections are very critical in a high density device.

Table 4.1.3.1.1-1 presents a summary of microcircuit failure mechanisms. This table identifies the points in the fabrication process at which a defect is introduced, the resulting failure mechanisms and modes, and the failure detection methods useful for screening the defects.

Since the failure mechanisms for microcircuit devices are the same regardless of whether they are operating or non-operating, the same part selection and control guidelines apply when selecting microcircuits for both operating and dormant designs. Optimum part selection should be aimed at assuring zero latent defects Present in the parts selected. It is impossible, however, to obtain parts with zero latent defects and tradeoffs will have to be made between cost, reliability, and other factors. Parts most thoroughly screened for defects are those chosen from a MIL-M-38510 QPL vendor. Therefore, whenever possible, parts for use in military and aerospace systems that will experience significant periods of dormancy should be chosen from a MIL-M-38510 QPL vendor.

Considering that compromises and tradeoffs are inevitable, Parts may sometimes have to be chosen from lower classifications. For example, there are many microcircuits that are procured to MIL-STD-S83 Class S or Class B screening that are not qualified to a MIL-M-38S1O QPL because their manufacturing process did not conform to MIL-M-38510 in-process controls. These devices could be selected as second alternatives to QPL parts. There also exist various lower quality grades of devices such as "vendor classes" and commercial grades. Since such lower grade devices frequently contain contamination and latent defects, they should not be used for dormant designs without additional screening to eliminate these defects (See Section 4.1.3.4).

The need to provide the most capability in an equipment design often necessitates the use of new devices and technologies. Where possible, devices that have demonstrated successful age histories and inherently good storage characteristics should be used. Where there is a lack of data concerning non-operating failure modes, mechanisms, and rates, devices must be carefully evaluated for potential non-operating failure modes and mechanisms prior to use. This evaluation should include accelerated aging tests (See Section 5) and material compatibility studies.

Table 4.1.3.1.1-1. Microcircuit Defects/Screens (Ref. 1)

Point at Which a Reliability-Influencing Variable is Introduced	Failure Mechanism	Failure Mode Method	Failure Detection
Slice Preparation	Dislocations and stacking faults	Degradation of junction characteristics	Initial electrical test; operational-life tests
	Nonuniform resistivity	Unpredictable component values	Initial electrical test; operational-life tests
	Irregular surface	Improper electrical performance and/or shorts, opens, etc.	Initial electrical test; operational-life tests
	Cracks, chips, scratches (general handling damage)	Opens, possible shorts in subsequent metallization	Initial electrical tests; visual (pre-cap); thermal cycling
	Contamination	Degradation of junction characteristics	Visual (pre-cap); thermal cycling; high temperature storage; reverse bias
Passivation	Cracks and pin holes	Electrical breakdown in oxide layer between metallization and substrate; shorts caused by faulty oxide diffusion mask	High-temperature storage; thermal cycling; high-voltage test; operating-life test; visual (pre-cap)
	Nonuniform thickness	Low breakdown and increased leakage in the oxide layer	High-temperature storage; thermal cycling; high-voltage test; operating-life test; visual (pre-cap)
Masking	Scratches, nicks, blemishes in the photo mask	Opens and/or shorts	Visual (pre-cap); initial electrical test
	Misalignment	Opens and/or shorts	Visual (pre-cap); initial electrical test
	Irregularities in photoresist patterns (line widths, spaces, pinholes)	Performance degradation caused by parameter drift, opens, or shorts	Visual (pre-cap); initial electrical test
Etching	Improper removal of oxide	Opens and/or shorts or intermittents	Visual (pre-cap); initial electrical test; operational-life test
	Undercutting	Shorts and/or opens in metallization	Visual (pre-cap); initial electrical test

Table 4.1.3.1.1-1. Microcircuit Defects/Screens (Ref. 1) (Continued)

Point at Which a Reliability-Influencing Variable is Introduced	Failure Mechanism	Failure Mode Method	Failure Detection
Etching	Spotting (etch splash)	Potential shorts	Visual (pre-cap); thermal cycling; high-temperature storage; operational-life test
	Contamination (photo-resist, chemical residue)	Low breakdown; increased leakage	Visual (pre-cap); initial electrical test; thermal cycling; high-temperature storage; operational-life test
Diffusions	Improper control of doping profiles	Performance degradation resulting from unstable and faulty passive and active components	High-temperature storage; thermal cycling; operational life test; initial electrical test
Metallization	Scratched or smeared metallization (handling damage)	Opens, near opens, shorts, near shorts	Visual, (pre-cap); thermal cycling; operational-life test
	Thin metallization to insufficient deposition or oxide steps	Opens and/or high-resistance intraconnections	Initial electrical test; operational-life test; thermal cycling
	Corrosion (chemical residue)	Opens in metallization	Visual (pre-cap); high-temperature storage; thermal cycling; operational-life test
	Misalignment and contaminated contact areas	High contact resistance or opens	Visual (pre-cap); initial electrical test; high-temperature storage; thermal cycling; operational-life test
	Improper alloying temperature or time	Open metallization, poor adhesion, or shorts	Initial electrical test, high-temperature storage; thermal cycling; operational life tests
Die Separation	Improper die separation resulting in cracked or chipped dice	Opens and potential opens	Visual (pre-cap); thermal cycling; vibration; mechanical shock; thermal shock

Table 4.1.3.1.1-1. Microcircuit Defects/Screens (Ref. 1) (Continued)

Point at Which a Reliability-Influencing Variable is Introduced	Failure Mechanism	Failure Mode Method	Failure Detection
Die Bonding	Voids between header and die	Performance degradation caused by overheating	X-ray; operational-life; acceleration, mechanical shock; vibration
	Overspreading and/or loose particles of eutectic solder	Shorts or intermittent shorts	Visual (pre-cap); X-ray; monitored vibration; monitored shock
	Poor die-to-header bond	Cracked or lifted die shorts	Visual (pre-cap); acceleration; shock, vibration
	Material mismatch	Lifted or cracked die	Thermal cycling; high-temperature storage; acceleration
	Overbonding and underbonding	Wire weakened and breaks or is intermittent; lifted bond; open	Acceleration; shock; vibration
Wire Bonding	Material incompatibility or contaminated bonding pad	Lifted lead bond	Thermal cycling; high-temperature storage; acceleration, shock, vibration
	Plague formation	Open bonds	High-temperature storage; thermal cycling; acceleration, shock, vibration
	Insufficient bonding pad area or spacings	Opens or shorted bonds	Operational-life test; acceleration, shock, vibration; visual (pre-cap)
	Improper bonding procedure or control	Opens, shorts, or intermittent operation	Visual (pre-cap); initial electrical test; acceleration, shock, vibration
	Improper bond alignment	Opens and/or shorts	Visual (pre-cap); initial electrical test
	Cracked or chipped die	Open	Visual (pre-cap); high-temperature storage; thermal cycling; acceleration, shock vibration

Table 4.1.3.1.1-1. Microcircuit Defects/Screens (Ref. 1) (Continued)

Point at Which a Reliability-Influencing Variable is Introduced	Failure Mechanism	Failure Mode Method	Failure Detection
Wire Bonding (Continued)	Excessive loops, sags or lead length	Shorts to case, substrate, or other leads	Visual (pre-cap); X-ray; acceleration, shock, vibration
	Nicks, cuts, and abrasions on leads	Broken leads causing opens or shorts	Visual (pre-cap); acceleration shock vibration
	Unremoved pigtails	Shorts or intermittent shorts	Visual (pre-cap) acceleration, shock, vibration; X-ray
Final Seal	Poor hermetic seal	Performance degradation; shorts or opens caused by chemical corrosion or moisture	Leak tests
	Incorrect atmosphere sealed in package	Performance degradation caused by inversion and channeling	Operational-life test; reverse bias, high-temperature storage, thermal cycling
	Broken or bent external leads	Open circuit	Visual; lead fatigue tests
	Cracks, voids in kovar-to-glass seals	Shorts and/or opens in the metallization caused by a leak	Leak test; electrical test; high-temperature storage, thermal cycling; high-voltage test
	Electrolytic growth of metals or metallic compounds across glass seals between leads and metal case	Intermittent shorts	Low-voltage shorts
	Loose conducting particles in package	Intermittent shorts	Acceleration; monitored vibration; X-ray; monitored shock
	Improper marking	Completely inoperative	Electrical tests

The following presents some additional lessons learned in the use of microcircuits in dormant designs:

- Do not use microcircuits that contain nichrome-deposited resistors. They are susceptable to electrolysis with trace amounts of moisture and they are subject to deterioration and failure at contact interfaces with aluminum conductors due to interdiffusion.

- Do not use microcircuits with gold-aluminum systems that have not been determined to be free of "purple plague" problems. During bonding and subsequent packaging operations, gold-aluminum wire bonds form intermetallic phases. Reliable gold-aluminum bonds can be made. It is necessary to minimize the total mass of aluminum available for diffusion and to keeP to a minimum the cumulative time-temperature product experienced by the device in both fabrication and use. Design limits for using gold-aluminum bonds can be found in reference 27.

- Analysis indicates that a single metal should be used for the contact metallization and interconnection interface. The all-aluminum system shows a definitely more reliable non-operating capability than the aluminum metallization/gold wire system. (Ref. 26)

- Do not seal chlorine or other halogen-containing materials within microcircuit devices.

- Polymers used within microcircuits should be simple hydrocarbons or compounds of carbon, hydrogen, and oxygen. Nitrogen containing polymers should be considered with skepticism. Ammonia and amines from curing epoxy resins can react with ions to form complexes and with acids or water to form cations. (Ref. 3)

4.1.3.1.2 Hermetic Hybrid Microcircuits

A hybrid microcircuit consists of a combination of solid state active circuit components (integrated circuits or discrete), thin or thick film-deposited passive elements, and other discrete components, interconnected by film patterns on one or more substrates in a single package to perform one or more circuit functions. Hybrid microcircuits are most commonly classified as either thin or thick film. In a thin film circuit, the mean free path of the current carriers (usually electrons) is comparable in length to the thickness of the film, usually in the range of a few thousands Angstroms. The film circuit is either vapor-deposited, vacuum-evaporated, or sputtered. In a thick film circuit, the film circuit is dePosited by screen printing (or spraying) with subsequent air drying and high temperature firing steps. Thick film thickness overlays the range of thin film thickness and extends to approximately 2.5 mils. (Ref. 18)

A hybrid microcircuit has the characteristics of both a monolithic microcircuit and a printed circuit board. It is analogous to a printed circuit board in that the hybrid is a functional assembly consisting of a variety of solid state and passive devices connected on a substrate (analogous to the printed circuit board), with electrical paths defined by conductor Patterns on the substrate. It is similar to a monolithic microcircuit in that the hybrid assembly is contained in a single package which is similar in size, appearance, and function to a conventional monolithic microcircuit. In the most general sense, hybrids are not as much a device type as a packaging technology with provisions for multiple devices of various types and the required conductor Patterns ro connect these devices in a functional manner. They are usually specified, procured, and used in a manner similar to monolithic microcircuits.

Hybrids are often used in specialized applications where off-the-shelf monolithic microcircuits which meet the design requirements are not available, and the cost of a custom monolithic microcircuit is prohibitive. Hybrid technology also offers the designer a means of implementing specialized functions involving very tight tolerances, thermal constraints, or other critical parameters which may not be available in conventional designs. For example, hybrid fabrication techniques permit a high degree of thermal coupling between adjacent semiconductor chips not easily achievable in conventional printed circuit board designs making thermal compensation circuitry relatively easy in hybrids. (Ref. 28)

Hybrid failure mechanisms include all those listed for monolithic devices plus those that are unique to the hybrid technology. Hybrid devices exhibit problems as a result of the number of different materials used in one package, the number of interconnections and bonds, the amount of processing with the chance of error or inclusion of contaminants, and hermetic sealing of a larger package. Materials must be carefully selected and the processing must be carefully controlled to prevent thermal mismatches between materials; leaching, diffusion, and migration of materials; intermetallic compound formations; and corrosion. (Ref. 18)

Tables 4.1.3.1.2-1 and 4.1.3.1.2-2 summarize the mechanisms unique to thick and thin film hybrid devices. Most of the mechanisms described are detectable during processing and screening.

In thick film devices, the faulty substrate bond or cracked substrate which is not detected during processing will be accelerated to failure by mechanical vibration and shock. The frequency of this failure, whether the device is operating or dormant, is dependent upon the frequency and level of mechanical vibration and shock experienced by the

Table 4.1.3.1.2-1. Hybrid Thick Film Failure Mechanisms (Ref. 18).

Failure Mechanism	Cause	Accelerating Environment	Failure Mode	Detection Method
Substrate				
Faulty Substrate Bond	Insufficient or Incomplete Substrate Bonding	Mechanical Stress	Open	Electrical Test
Cracked or Broken Substrate	1) High Thermal stressed during processing	Mechanical Stress	Open	Precap Visual, Electrical Test
	2) Thin Substrate	Mechanical Stress	Open	Precap Visual, Electrical Test
Film Resistors				
Damaged Resistor	1) Overspray of abrasive trimming material to adjacent resistors during processing		Open or out of tolerance	Electrical Probing
	2) Electrostatic discharge during processing		Open or out of tolerance	Electrical Probing
	3) Leaching or diffusion at resistor-conductor-interface	Hi Temperature	Open or out or tolerance	
Cracked Resistor	1) Insufficient quantity of slow drying solvent, wetting agent, or flow control additive		Open	Electrical Probing
	2) Mismatch in thermal coefficient of expansion of the resistor, conductor and ceramic substrate	Thermal Cycling	Open	Electrical Probing
Out-of-tolerance	1) Palladium-silver resistor change in hydrogen atmosphere		Out of tolerance	Electrical Probing
	2) Hot spots at sharp corners or resistors		Out of tolerance	Infrared scanning prior to capping

Table 4.1.3.1.2-1. Hybrid Thick Film Failure Mechanisms (Ref. 18). (Continued)

Failure Mechanism	Cause	Accelerating Environment	Failure Mode	Detection Method
Chip Elements				
Faulty Bonds	1) Insufficient or incomplete bonding	Mechanical Stress	Open	Bond Pull Test, Electrical Test
	2) Leaching of silver-gold-solder combinations	Mechanical Stress	Open	Bond Pull Test, Electrical Test
	3) Glass Frit Fracture	Mechanical Stress	Open	Bond Pull Test, Electrical Test
Cracked Dice	Mechanical stress during processing	Thermal & mechanical Stress	Open	Precap Visual, Electrical Test
Conductors				
Shorted Conductors	1) Silver migration 2) Holes in glass insulation at crossover or insufficient thickness of glass	High Current Density with potential difference	Short	Precap Visual, Electrical Test
Shorted Interconnecting Wires	1) Downbonding from a higher surface to a lower one	Thermal & Mechanical Stresses	Short	Precap Visual, Electrical Test
	2) Improper lead length	Thermal & Mechanical Stresses	Short	Precap Visual, Electrical Test
Faulty Bonds	Insufficient or Incomplete Bonding	Thermal & Mechanical Stresses	Short	Precap Visual, Electrical Test
Capacitive Coupling	Long parallel conductors resulting in capacitive coupling		Out-of-tolerance	Electrical Test

Table 4.1.3.1.2-2. Hybrid Th Film Failure Mechanisms (Ref. 18).

Failure Mechanism	Cause	Accelerating Environment	Failure Mode	Detection Method
<u>Substrate</u>				
Cracked Substrate	Thermal & Mechanical Stresses during Processing	Thermal & Mechanical Stresses	Open	Precap Visual, Substrate Capacitance Measurements, Electrical Test
Craters or Pits in Substrate	Grain size uncontrolled and large grains pulled out during lapping, buffing or polishing.		Out-of-tolerance	Precap Visual
<u>Element Films</u>				
Drift of Electrical Parameters	1) Surface Alkali Concentrations	Thermal Cycling	Out-of-tolerance	Electrical Test
	2) Diffusion of Alkali Ions from Substrate into resistor film	Thermal Cycling		
	3) Uneven surface			
	4) Separation of Nichrome during disposition			
	5) Thermal coefficient of expansion mismatch between film and substrate	Thermal Stresses		
	6) T_iO_2 film exhibiting semi-conductor properties			
	7) Ionic migration between resistor strips	Hi Voltage & Temperature		
	8) Excess die bonding times and temperatures			
Cracked or Open Element	Thermal runaway due to constriction and oxidation		Open resistor, open or shorted capacitor	Electrical Test

Table 4.1.3.1.2-2. Hybrid Thin Film Failure Mechanisms (Ref. 18). (Continued)

Failure Mechanism	Cause	Accelerating Environment	Failure Mode	Detection Method
Element Films (Cont.)				
Shorted Capacitor	Explosion of gases during vaporization		Short	Precap Visual, Electrical Test
Chip & Wire Bonding				
Bond Separation	1) Insufficient Bonding 2) Damage caused by probe testing	Thermal & Mechanical Stresses	Open	Precap Visual Electrical Test

device, usually as a result of the transportation and handling of the equipment in which the device is used.

The failure mechanisms for thick film resistors include processing failures not detected during device screening, defects that are accelerated by high temperature or thermal cycling, and corrosion. The rate of occurrence of the last two groups of defects are dependent upon factors in the non-operating environment.

The chip element failure mechanisms in thick film devices are the same as those experienced by monolithic devices except that bonding materials and processes may be different.

The number of conductors and interconnections in the hybrid device can lead to shorted conductors, faulty bonds, etc. Defects of this type are accelerated to failure by thermal/mechanical stresses. Since silver migration depends uPon a high current density, its rate of occurrence will be decelerated during non-operating periods.

Aluminum-Silver bonds are highly susceptable to corrosion if moisture is present. The corrosion is accelerated at high temperature and in the presence of halogen contaminants such as NaCl, etc. Significant degradation can occur at room temperature and moderate humidity levels. Prior thermal aging in the 100 to 200 degree C range increases the susceptability to degradation. The use of an Ns4OH-Hzo ultrasonic bath to remove chlorine and vacuum bakes to minimize moisture and other volatile contaminants before sealing has been shown to markedly reduce Aluminum-Silver bond degredation. (Ref. 29)

The failure mechanisms for thin film devices are similar to those experienced by thick film devices. The failure mechanisms that are unique to thin film devices are those associated with the element films. The rate of occurrence of these defects is dependent upon the environment, with many of them being accelerated to failure by thermal stresses.

4.1.3.2 General Characteristics of Non-Hermetic Microcircuits

As the name implies, non-hermetic microcircuits are devices that are encapsulated in packages that do not provide a hermetic seal. Common non-hermetic packaging methods include plastic encapsulation and polymer sealing of open cavity packages. Because they do not provide a hermetic seal, non-hermetic packages will not protect microcircuit devices from the effects of atmosPheric moisture and other contaminants. As stated in section 4.1.3, the overwhelming area of concern for long-term non-operating reliability of microcircuit devices is the influence of chemical contaminants, particularly moisture. Since they are not protected from these contaminants, non-hermetic microcircuits should, as a general rule, be avoided for dormant designs.

There may be situations, however, when the use of non-hermetic devices are contemplated for dormant designs because of cost or other factors (e.g. shock resistance) favoring their use. To assist in these decisions the following information is provided. Section 4.1.3.2.1 addresses plastic encapsulated devices (PEDs) and Section 4.1.3.2.z addresses polymer-sealed devices.

4.1.3.2.1 Plastic Encapsulated Devices

In contrast to hermetic and polymer-sealed devices which are sealed in an open cavity, PEDs are completely enclosed (except for the leads) in a dielectric material by transfer molding or other encapsulating method. Materials commonly used for encapsulation include epoxies, silicones, and phenolics. The advantages of plastic encapsulation include lower cost, mechanical shock and vibration resistance, freedom from loose particles, and smaller package sizes. While new techniques and materials continue to be developed, all plastics contain moisture and are permeable to moisture to some degree. Figure 4.1.3.2.1-1 illustrates the relative effectiveness of various sealant materials as moisture barriers.

In addition to being transported through the package material, moisture also enters PEDs along imperfect plastic/lead bonds. While several plastics have extremely low moisture vapor transmission rates through the bulk material, the interface between the metal and plastic is an abrupt discontinuity in composition, expansion coefficient, and structure. The forces holding the surfaces together are weak with little or no chemical bonding taking place making moisture barrier tightness largely due to the bulk mass of the plastic compressing the lead. Cracks can develop as a result of temperature cycling and lead bending during fabrication and handling prior to fabrication. (Ref. 30)

Passivation coatings are widely used to improve the performance and reliability of microcircuits in both hermetic and non-hermetic packages. Passivation coatings in direct contact with the device chip are classified as primary and passivation coatings that are separated from the device chip by an underlying dielectric layer are classified as secondary. The function of the primary passivation layer is to provide good dielectric properties, low surface recombination velocity, controlled immobile charge density, and device stability. The function of the secondary passivation layer is to provide additional stability in various ambients, in both production and use, and to serve as getter, impurity barrier, or mechanical shield. As a barrier

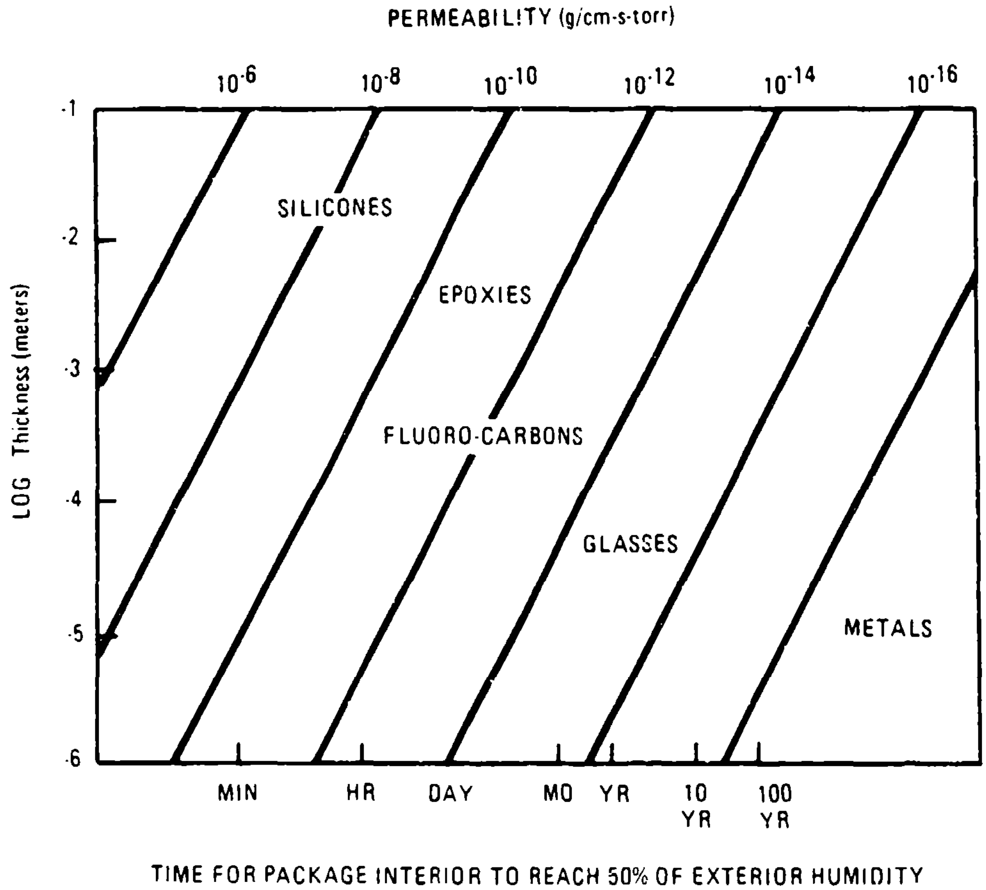

Figure 4.1.3.2.1-1. Effectiveness of Sealant Materials (Ref. 3)

against ambient effects, passivation layers provide only partial protection. For example, while silicon-nitride devices may be protected against alkali penetration into an underlying silicon dioxide layer, they may become susceptible to potential buildup at insulator-insulator interfaces or at the ambient-upper dielectric interface. For a more detailed discussion of passivation coatings, the interested reader is referred to reference 33.

The thermal properties of epoxies and silicones are also a limiting factor in the use of PEDs. While most military systems require device operating temperatures of 55°C to +125°C, most PEDs are only rated for 0°C to 70°C. The limiting thermal characteristics are the glass transition temperature (e.g. 225°C for silicon and 124°C for epoxy Novolac) and the thermal coefficient of expansion. If the temperature of the plastic device is not kept below the glass transition temperature, severe changes in the nature of the Plastic material will occur along with sharp increases in the coefficient of expansion (Ref. 31). Mismatches in the thermal coefficients of expansion between the encapsulating material and the other device materials such as the lead frame and bond wires can lead to bond failures under thermal cycling conditions.

The sensitivity of PSDs to salt environments is dependent upon the encapsulating material. Tests performed in Panama by the US Army (Ref. 32) have shown that Epoxy Novalac devices are relatively unaffected by a salt environment while silicone devices are very susceptible to NaCl penetration resulting in contact metallization deterioration in devices with aluminum metallization and gold dendritic growth in devices with gold metallization.

One situation where PEDs have shown a definite advantage over hermetic devices is in applications with high levels of mechanical shock and vibration (e.g. cannon launch). In an encapsulated device the entire device (i.e. chip, lead bonds, etc.) is encased in plastic. As a result of this, only the most severe external mechanical stresses adversely affect them. In addition, because the encapsulating material is in direct contact with the chip, failures due to particulate contamination, a source of failure in open cavity packages difficult to detect during screening, is eliminated.

In a 1984 study (Ref. 31) of the main factors governing the relative reliability and applicability of plastic commercial, hermetic commercial, and JAN-qualified microcircuits, the Reliability Analysis Center at the Rome Air Development Center, Griffiss AFB, presented the following conclusions and recommendations concerning the application of PEDs in military equipment:

- Certain families of devices have experienced severe problems in plastic encapsulation. These include low power dissipation devices, linear devices, and recent technologies. Bipolar TTL-type devices have performed best in plastic encapsulation.

- The long-term, high-stress, and non-operating reliability of PEDs has not been determined and cannot be assumed.

- Screening programs differ from manufacturer to manufacturer and should be examined to assure that the procedures address known PED failure mechanisms, including intermittent internal connections, chip surface effects, corrosion, contamination and those resulting from marginal manufacturing anomalies.

- The Purchase cost savings associated with commercial PEDs does not include any custom or unique Parts. Large cost savings are for industry-standard part types, most sPecifically SSI/MSI and memory Parts.

- Special screens above and beyond the manufacturer's standard in-house screens will upset the normal high-volume flow of production and delivery cycle and should be expected to cause significant cost increases.

- When selecting manufacturer's, select those in continuous volume production of mature products for which they are willing to make a reliability commitment. Manufacturer's selected should conduct an in-house screening program and demonstrate high reliability when subjected to qualification tests.

- The quality of PEDs has been known to vary from manufacturer to manufacturer and even between lots from the same manufacturer. Manufacturers' products should be subjected to periodic qualification tests for approval.

- When employing PEDs, avoid part types which are known to experience reliability problems in plastic encapsulation.

- For best possible performance, PEDs must be used in an environment with strict temperature and humidity controls. High atmospheric salt concentration may also present a problem.

- When employing PEDs it is important to be assured that environmental controls are exercised during all stages of device life including manufacturer, shipping, storage, and operation.

4.1.3.2.2 Polymer-Sealed Devices

Polymer-sealed devices are similar to hermetically sealed devices except that the package is sealed with a polymer-sealing compound in place of the glass, metal, or ceramic used for hermetic seals. Because the seals are non-hermetic, these devices are not protected from the effects of atmospheric contaminants such as moisture. They have all of the disadvantages of PEDs concerning moisture and atmospheric contamination sensitivity with none of the PEDs advantages in the areas of mechanical shock and vibration resistance and freedom from loose particle contamination.

In an investigation of the reliability of plastic encapsulated and polymer-sealed hybrid microcircuits (Ref. 34), Mazenko and Hakim made the following conclusions:

- Polymer sealed, metal packaged hybrids are useful only in low humidity environments.

- Polymer seals deteriorate badly in moist environments. During testing the package sealing perimeter deteriorated so badly that the device lids fell off through routine handling and testing.

- Transfer molded devices survive moist environments better than polymer-sealed devices.

Based upon these findings, polymer-sealed microcircuits are not recommended for dormant equipment designs.

4.1.3.3 VLSI/VHSIC Microcircuits

VLSI and VHSIC devices are taxing the constraints of existing fabrication processes and equipments. Geometries are exceeding the limits of conventional photolithographic techniques requiring the use of new techniques such as electron beam, ultraviolet. and x-ray lithography. Also a problem is the chemical etching process used to define the metallization pattern on the surface of the chip, where process control has limited line widths and spacings. Limitations in the conventional photolithographic mask generation and registration process has also resulted in the use of new diffusion techniques.

The multiple layer structure for VHSIC devices presents several additional concerns and potential failure mechanisms. Step metallization integrity is aggravated with increasing step count and becomes most compromised in the uppermost layer. Due to smaller metallization widths and thicknesses the problem of detection becomes important, yet visual inspection of all metallization is not feasible in multilayer structures. Further, MOS devices employing polysilicon in their fabrication are subject to a unique mechanism. The integrity of the dielectric which interfaces with the polysilicon is in question due to the tendency of polysilicon to nucleate into large grains at the interface, causing disturbances at this interface (Ref. 28).

Interconnects are an important aspect of reliability in VLSI and VHSIC devices. As more devices are integrated on a chip, a higher percentage of the chips area is occupied by interconnects which are prone to failure from electromigration, whisker formation, faulty ohmic contacts, corrosion, and masking faults. This makes these devices more susceptible to moisture related problems.

A technique being considered for electrical connection bonds on VHSIC devices is solder bumps. This technique must be carefully evaluated in dormant designs since it has been noted that they are susceptible to fatigue from mechanical stress. Electrical bonds are a prime reliability concern since not only are the bonds smaller, but there are a much larger number of them. (Ref. 28)

Contamination and latent defects introduced during the fabrication process are a primary determinant of long-term non-operating reliability in all microcircuits. This is especially true for VLSI and VHSIC devices. The dry etching process which is to be widely used in VHSIC fabrication uses a chlorine based gas (Ref. 28). Any residual chlorine remaining in the device package will have catastrophic effects on long-term non-operating reliability.

Stray particle contamination during fabrication will also have adverse consequences as a result of the extreme device scaling. The thin oxide layers of VLSI and VHSIC devices are approaching the diameter of the minimum size particle that can be effectively removed in clean room air filtration. A high density of 50-100 angstrom particles may exist in a class 10 clean room (Ref. 28). Such particles can cause problems such as oxide defects, crystaline structure defects, and stacking faults.

The use of new materials may also impact device non-operating reliability. The use of polyimide as a dielectric between metallization layers will improve step coverage and alpha particle absorption, however, it is hydroscopic and will expand in the presence of water vapor, setting up mechanical stresses that can lead to device failure.

The chip size of VLSI and VHSIC devices is a factor in long-term non-operating reliability. Previous studies of power transistor dice bonded to copper headers have shown that such dice are subject to cracked die failure mechanisms if the silicon die is made larger than

250 mil square. This is due to the mismatch between the linear expansion coefficients of the die and the copper header during thermal cycling. VHSIC chips of 400 mil square and larger are currently being built and bonded to non-copper substrates. The performance of these devices in a thermal cycling environment must be carefully evaluated prior to using them in dormant applications.

4.1.3.4 Microcircuit Stress Screening

Experience has shown that most failures that occur during dormancy are of the same basic kind as those found in the operating mode and are the result of latent manufacturing defects. Screening of devices is, therefore, one of the most effective ways of improving the reliability of microcircuits in both the operating and non-operating environment.

Stress screening entails a combination of visual inspections, electrical tests, and the application of stress tests to a device with the purpose for revealing inherent weaknesses (and thus incipient failures) of the device without destroying the integrity of the device. Inferior devices will therefore fail and superior devices will pass.

Table 4.1.3.1.1-1 identifies microcircuit failure modes and mechanisms and the detection methods useful for screening them out. Table 4.1.3.4-1 compares the various screening methods in terms of cost effectiveness and effectiveness in screening the defects noted.

It is not feasible, however, to construct a comprehensive screening procedure that is able to remove all types of weak or defective microcircuits from a given population of devices. The potential failure mechanisms are numerous and device construction details are too diverse to realistically search out all weaknesses. There are a limited number of ways to observe and exercise the delicate composite structure of a microcircuit without undue damage to good devices. Some screen tests will rapidly extend a device population into the wear-out phase if the stress parameters are to severe. Latent defects can also be created during the screening procedure. This must be avoided.

Some of the defects important to dormant microcircuits are not revealed in reasonable times with current test methods. For example, it is necessary to destructively puncture a package to accurately determine if the moisture level is high. Furthermore, moisture induced failure modes often require longer time periods to develop than are practical with current screening stresses.

Table 4.1.3.4-1. Comparison of Screening Methods (Ref. 1)

Screen	Defects	Effectiveness	Cost	Comments
Internal visual	Lead dress Metallization Oxide Particle Die Bond Wire Bond Contaminaton Corrosion Substrate	Good	Inexpensive to moderate	This is a mandatory screen for high-reliability devices. Cost will depend upon the depth of the visual inspection.
Infrared	Design (thermal)	Very good	Expensive	For use in design evaluation only.
X-ray	Die Bond Lead Dress (gold) Particle Manufacturing (gross errors) Seal Package Contamination	Excellent Good Good Good Good Good Good	Moderate	The advantage of this screen is that the die-to-header bond can be examined and some inspection can be performed after encapsulation. However, some materials are transparent to X-rays (i.e., Al and Sl) and the cost may be as high as six times that of visual inspection, depending upon the complexity of the test system.
High temperature storage	Electrtical (stability) Metallization Bulk Silicon Corrosion	Good	Very inexpensive	This is a highly desirable screen.
Temperature cycling	Package Seal Die Bond Wire Bond Cracked substrate Thermal mismatch	Good	Very inexpensive	This screen may be one of the most effective for aluminum lead systems.
Thermal shock	Package Seal Die Bond Wire Bond Cracked substrate Thermal mismatch	Good	Inexpensive	This screen is similar to temperature cycling but induces higher stress levels.
Constant acceleration	Lead Dress Die Bond Wire Bond Cracked substrate	Good	Moderate	At 20,000 G stress levels, the effectiveness of this screen for aluminum is questionable.

Table 4.1.3.4-1. Comparison of Screening Methods (Ref. 1) (Continued)

Screen	Defects	Effectiveness	Cost	Comments
Shock (unmonitored)	Lead Dress	Poor	Moderate	The drop-shock test is considered inferior to constant acceleration. However, the pnuemopactor shock test may be more effective. Shock tests may be destructive.
Shock (monitored)	Particles Intermittent short Intermittent open	Poor Fair Fair	Expensive	Visual or X-ray inspection is pre-erred for particle detection.
Vibration fatigue	Lead Dress Package Die Bond Wire Bond Cracked substrate	Poor	Expensive	This test may be destructive. Except for working hardening, it is without merit.
Vibration variable frequency (unmonitored)	Package Die Bond Wire Bond Substrate	Fair	Expensive	
Vibration variable frequency (monitored)	Particles Lead Dress Intermittent open	Fair Good Good	Very expensive	The effectiveness of this screen for detecting particles is part-dependent.
Random vibration (unmonitored)	Package Die Bond Wire Bond Substrate	Good	Expensive	This is a better screen than VVF (unmonitored) especially for space-launch equipment, but it is more expensive.
Random vibration (monitored)	Particles Lead Dress Intermittent Open	Fair Good Good	Very Expensive	This is one of the most expensive screens; when combined with only fair effectiveness for particle detection, it is not recommended except in very special situations.
Helium leak test	Package Seals	Good	Moderate	This screen is effective for detecting leaks in the range of 10^{-8} to 10 Atm. cc/sec.
Radiflo leak teat	Package Seals	Good	Moderate	This screen is effectice for leaks in the range of 10^{8} to 10^{12} Attm cc/sec.
Nitrogen bomb test	Package Seals	Good	Inexpensive	This test is effective for detecting leaks between the gross-and-fine-leak detection ranges.

Table 4.1.3.4-1. Comparison of Screening Methods (Ref. 1) (Continued)

Screen	Defects	Effectiveness	Cost	Comments
Gross-leak test	Pacakge Seals	Good	Inexpensive	Effectiveness is volume-dependent. Detects leaks greater than 10 Atm. cc/sec.
High-voltage test	Oxide	Good	Inexpensive	Effectiveness is fabrication dependent.
Isolation resistance	Lead Dress Metallization Contamination	Fair	Inexpensive	
Intermittent operation life	Metallization Bulk Silicon Oxide Inversion/ Channeling Disign Parameter Drift Contamination	Good	Expensive	Probably no better than ac operating life.
Ac operating life	Metallization Bulk Silicon Oxide Inversion/ Channeling Design Parameter Contamination	Very good	Expensive	
DC operating life	Essentially the same as intermittent life.	Good	Expensive	No mechanisms are activated that could not be better activated by ac life tests
High-temperature ac operating life	Same as ac operating life	Excellent	Very expensive	Temperature acts to accelerate failure mechanisms. This is probably the most expensive screen and one of the most effective.
High-temperature reverse-bias	Inversion/ Channeling	Poor	Expensive	

4.1.4 Discrete Semiconductors

The failure modes and mechanisms for discrete semiconductors are the same as those identified in section 4.1.3 for microcircuits. As was true for microcircuits, most discrete semiconductor failures that occur during dormancy are of the same basic kind as those found in the operating mode and are the result of the further degradation of latent manufacturing defects which were not detected during device screening. The discussions and tables in section 4.1.3 regarding monolithic microcircuits are directly applicable to discrete semiconductors and will not be repeated here. Only differences between discrete semiconductors and microcircuits will be discussed in the following.

The difference between discrete transistors and microcircuits lies in the physical size, number, and complexity of manufacturing processes. Compared to the average integrated circuit, a transistor is a relatively simple device, with fewer number of junctions and leads. The distances between different parts of the device are larger and the manufacturing processes are fewer and simpler. Although the failure mechanisms are similar to those in microcircuits, the differences between microcircuits and discrete semiconductors tend to shift their emphasis. Bulk defects are more common due to the larger blocks of silicon required thus increasing the probability of crystal defects. Crystal defects collect mobilized contaminants resulting in breakdown, leakage, gain failures and, in high power devices, thermal runaway. Diffusion defects are not as critical due to the lower density of diffusions. Oxide and metallization defects are not as pronounced as in microcircuits because the metallization patterns are much simpler. (Ref. 18)

A large percentage of transistor failures are the result of die and wire bonding defects. Contamination, both ambient and within the material, is also a major problem in transistors. (Ref. 18)

The failure mechanisms for diodes are similar to those found in transistors. In addition to those mechanisms in Table 4.1.3.1.1-1, alloy bonded and point contact diodes can develop intermetallic compounds at the junction, however, this has not been identified as a severe problem. Loss of contact is also a potential problem is spring loaded contacts. This happens when the contact material loses its compression strength or by slipping off the contact. For these reasons, the use of spring loaded diodes with spring loaded contacts is not recommended for dormant applications. (Ref. 18)

4.1.5 Inductive (Magnetic) Devices

Inductive devices refer to a wide variety of components dependent upon a number of turns of wire designed to oppose a change in current flow in an electric circuit, to produce magnetic flux or to react mechanically to a changing magnetic flux. There are three categories of inductive devices covered in this section: transformers, coils, and inductive filters. Standard magnetic devices are listed in MIL-STD-1286 (Ref. 39) and are selected from among devices covered by applicable MIL specifications. Most transformers, inductors, and coils used in military aerospace applications are custom designed for minimum size and width to fit available space in compact equipment. As a result, relatively little standardization of electrical parameters has occurred. However, a family of standard sizes should be used whenever possible, even if the electrical characteristics of the, new devices are unique. (Ref 1)

Inductive devices create a magnetic field derived from the Physical construction of the device and its electrical input.

A coil is simply several turns of wire around a supporting structure. Since inductive operation depends on the physical arrangements of the wire, provisions are taken to prevent contact between adjacent wire turns. This is accomplished by insulating the wire. Potting the entire device also provides insulation and provides additional mechanical strength. (Ref 18)

A transformer is a device consisting of two or more coils coupled together by magnetic induction. Its main components are input and output coils and a core around which the coils are wound. As in the case of the simple coil, the wire turns in the input and output coils must be insulated from each other. (Ref 18)

An inductive filter is a network designed to selectively block or allow passage of certain frequencies or bands of frequencies. It is comprised of several coils in network form mounted n a supporting structure such as a printed circuit board or any other suitable means. In its basic form the RF choke can be considered the simplest form of inductive filter. (Ref 18)

The selection of a transformer, inductor, or coil depends upon many factors. These factors include: function, construction, circuit application, operating temperature, altitude, type of mounting, environmental conditions, size and weight, life expectancy, and reliability. After the preliminary selection of a transformer, inductor, or coil has been made, the appropriate specifications and military standards should be examined to verify that the item is capable of performing satisfactorily in the intended application and that parameters important to the new application are controlled to the degree necessary. (Ref 35)

Shorts are usually the result of the breakdown of insulation. During dormancy, insulation breakdown is the result of chemical changes and deterioration accelerated by temperature, humidity and reactions with atmosphere gases. (Ref 1)

Therefore, selection of insulating materials is of paramount importance. Inductive devices must function satisfactorily under a variety of environmental conditions to which they are exposed. Life testing of insulation used for inductive devices has identified that: vibration is not a significant factor in transformer life, humidity is also not a major factor (humidity effects reduce the life of transformers by a slow change in resistivity between windings), thermal cycling appears to bring about the largest decrease in life expectancy. (Ref 37)

Thermal aging mechanisms for insulating materials is complex and varies with material composition and service conditions. Typical mechanisms of degradation include: (Ref 15)

- Loss of volatile constituents such as low molecular weight compounds present in the original insulating materials arising from processes of manufacture or compounding, or formed as products of the aging process.

- Oxidation, which may result in cross-linking and embrittlement or the production of volatile materials.

- Continuing molecular polymerization, which may result in an initial increase in physical and electric strength, but subsequently causes decreased flexibility, embrittlement, and failure under mechanical stress.

- Hydrolytic cleavage by reaction with moisture under the influence of heat and other factors leading to molecular breakdown.

- Chemical breakdown of constituents with formation of degradation products typified by the liberation of hydrochloric acid which in turn, may catalyze further decomposition.

The degradative processes classified above may be retarded or effectively suppressed by the addition of stabilizing materials. Oxidative breakdown may be controlled by addition of antioxidants. Liberation of hydrogen chloride, which is specific for vinyl chloride polymers and is reported to exert a catalytic influence on further decomposition, is minimized by addition of basic acid absorbing materials. (Ref 15)

Different insulating materials react to a different degree and in different ways to the aging processes. Their thermal performance cannot, therefore, be reliability predicted from the chemical composition of the material. The thermal aging process may at first lead to increased strength due to loss of volatiles and additional polymerization, followed by loss of the strength and embrittlement. In other cases, especially in closed systems, the buildup of degradation products may lead to softening. (Ref 15)

The thermal capability of insulating materials is an important factor in determining the performance of electronic equipment. Interest, therefore, centers on accelerated life tests to determine appropriate limiting temperatures and fields of usefulness for various insulating materials and systems. (Ref 15) The designer should refer to Reference 15 for a more detailed discussion of aging mechanisms in insulating materials.

The most common insulation system of power transformers generally consists of cellulosic paper and pressboard impregnated with mineral oil. The life of such a system is governed by the oxidation and thermal decomposition of the cellulose, oxidation of the oil and catalytic effects of the degradation products. The replacement of the paper insulation with more stable materials offers the best hope for improvement in the life of insulation systems. (Ref 36)

There are two basic problems hindering the use of new materials. First, there is a need for improved correlation between the results of life tests conducted on the material itself and its performance in the insulation system of the transformer. Second, there is no reliable method available for measuring the life of a complete transformer without testing a full size unit. (Ref 36)

Opens in inductive devices result from the breaking of the fine winding wire. Unless caused by mechanical shock or stresses, opens are normally associated with manufacturing problems such as stress in relief loops, wire nicks, and soldering of lead wires to the windings. (Ref 1) Failure modes for inductive devices are accelerated by environmental conditions. The effects of various environments in operational or dormant applications is summarized in Table 4.1.5-1.

Table 4.1.5-1. Failure Modes Affected By Various Use and Storage Conditions

Component	Vibration Effects	Shock Effects	Temperature Effects	Humidity Effects	Salt Spray Effects	Storage Effects
Transformers	Shorts: opens; modulation of output	Shorts; opens; modulation of output	Reduced dielectric; opens; shorts; hot spots; malformation	Corrosion; fungus shorts; opens	Corrosion; shorts;	Deterioration of potting and dielectric
Coils	Loss of sensitivity detuning; breaking of parts, leads, and connectors	Lead breakage; detuning; loss of sensitivity	Warping, melting; instability; change in dielectric properties	Electrolysis; corrosion	Corrosion; electrolysis	

4.1.6 Relays

There are two basic types of relays: electromechanical and solid-state. In an electromechanical device, mechanical linkages are actuated by an electrical coil which joins or separates electrically conductive mechanical contacts. Solid-state relays are divided into two categories: pure solid-state and hybrids. Pure solid-state relays accomplish their switching functions by means of an arrangement of semiconductors and passive devices. Hybrid relays are a combination of solid-state circuitry and electromechanical linkages in a single package. The solid-state circuit drives the electromechanical relay to perform the switching function. (Ref 1)

These relay types are further subdivided by functional classifications, which include: Balanced armature, balanced-force, low-level, magnetic latching, and polarized types. Balanced armature type relays have the armature pivoted at the center of the mass, which balances the armature with respect to static and dynamic external forces. This type works better than other types in shock and vibration environments. (Ref 35)

4.1.6.1 Solid-State Relays

This section addresses pure solid-state relays (i.e., relays with no mechanical components). Solid-state relays are primarily semiconductor devices, and are particularly well suited for dormant applications. These devices are generally completely sealed units and they undergo minimal environmental degradation.

Sections 4.1.3 ands 4.1.4 of this text are applicable to solid-state relays.

4.1.6.2 Electromechanical Relays

This section addresses electromechanical devices, it includes any type of relay with mechanical components. The storage life of hermetically sealed relays, with proper materials and processes employed to eliminate outgassing, is in excess of 10 years. (Ref 24) Designers should consult Reference 11 to identify potential material outgassing effects.

The chief problem in electromechanical relays, whether in a dormant or operational configuration is contamination. Relay contamination can occur if the construction of the relay is not matched to its applied environment.

Corrosion of metal parts used in electromechanical relays will occur in humid environments. Dust, sand, or other contaminants will damage, block, or degrade relay contacts if contacts are not properly protected. Fungus growth on coils will degrade performance.

Mechanical shock generally causes failure in the form of the armature failing to hold during the shock.

An electromechanical relay should not be used when a solid-state relay can satisfy the application, or when the application can be tailored to enable the use of a solid-state relay. When it is necessary to employ electromechanical relays, redundancy should be employed whenever high reliabilty is required. (Ref. 24)

The analysis conducted to define the redundancy configuration should not only consider the circuit application, but also the characteristics and failure mechanisms of the specific candidate relay. Failure mechanisms should be explored very thoroughly as the different types of mechanical arrangements combined with manufacturing variability can produce unexpected modes such as partial, intermittent, closing of the relay. The parallel redundant configuration is the most commonly used approach since it protects against the open failure mode resulting from particle contamination. Quad redundancy may be necessary if the potential metallic contamination is large compared with the contact gap, as has been experienced with some relays. One form of quad redundancy consists of two coils (two relays) with two contacts within each relay.

When the use of electromechanical relays is unavoidable, the guidelines presented herein will increase the reliability of these devices in dormant applications. Section 4.1.6.2.1 presents design guidelines and section 4.1.6.2.2 presents process control guidelines to electromechanical relays.

4.1.6.2.1 Design Guidelines

The design guidelines presented are both application independent and application dependent. The guidelines are subdivided under these two groupings. (Ref 24)

Application Independent

- Relays should be hermetically sealed for minimum leakage. Electron beam welding should be used. This type of seal has the least leakage and introduces practically zero contamination.

- Do not use a getter. If cleaning processes and material selection require a getter, the relay is not a high reliability relay. In addition, getters are a source of particulate contamination.

- Use compression glass for pin seal. To minimize susceptibility to cracking, undercut the front and back side of header. This will puddle the glass and prevent miniscule creep.

- Do not use built-in devices for ac rectification (coil) or induced voltage suppression. These additional components decrease reliability through particle contamination and outgassing.

- Use balance clapper armature design. Although other designs appear to have higher reliability possibilities (suspended, rotary, diaphragm), each exhibits a weakness which results in less reliability (shock/vibration, particulate susceptibility, hydrocarbon outgassing).

Application Dependent

- For dry circuit (i.e., open circuit voltage $\leq$ 0.03V, current $\leq$ 200mA) to intermediate loads, use gold plating on contacts. The softness and inertness of gold reduces susceptibility to film contamination, which is the primary problem in this load range.

- For intermediate to high loads, use palladium for contact material. The hardness, high melting point and relatively inert properties reduce the susceptibility to material transfer, erosion and carbon generation.

- The tradeoff involved with backfill gas is: inert gas versus a gas with some oxygen for lubrication. Unfortunately, oxygen enhances polymer formation in addition to being an oxidizer. Small-ultra-clean-single-cavity-relays should use oxygen. Small dual-chamber relays should use oxygen in the contact chamber. These relays are more susceptible to sticking from self-adhesion due to the small motor forces and the noble metals use on contacts. There is some evidence that oxygen in larger relays is effective in reducing wear and particle contamination.

4.1.6.2.2 Process Control Guidelines

- Coil wire lubricant is a major cause of hydrocarbon contamination. Wind the coil, using dry wire. This can be done by immersing, the spool in a bath of trichlorethylene and wiping the strand during winding.

- Coil wire should be pretensioned during winding operations at just below the elastic limit. Scramble wound is preferred, as space factor is just under layer wound, and it is easy.

- All subassembly components (armature, frame, can, contacts, header, pins, bobbin, springs and pins) should be cleaned prior to assembly. The recommended cleaning process is ultrasonic trichlorethylene, GN_2 drying, ultrasonic alcohol, gaseous nitrogen (GN_2) drying, ultrasonic distilled water followed by GN_2 drying.

- All handling/moving of components and subassemblies should be done with the components sealed in a plastic bag.

- All relays should be subjected to a high temperature, high vacuum degassing process. The vacuum should be less than 5 mm Hg, and the temperature at 200 degrees C for 4 hours minimum. At least one GN_2 purge cycle is recommended. The hydrocarbon outgassing which condenses on the chamber walls should be cleaned after each batch processing.

- Plating is a major source of metallic contaminants. Avoid plating, if possible. The plating material electrolyte, temperature time, etc., should be very precisely controlled. In addition, samples should be analyzed from every plating lot to assure uniformity, adhesion and porosity of plating.

4.1.7 Switches

Switches used in electronic equipment can be grouped into three basic types: rotary, non-rotary, and sensing.

Guidelines for switches in dormant applications are presented in section 4.1.7.1. Environmental effects and guidelines are presented in section 4.1.7.2.

4.1.7.1 Guidelines

A major problem with switches is contamination, both particles and contaminant films on contacts. The storage life of switches exceeds 10 years when the devices are hermetically sealed and internal nonmetallic materials are eliminated, or if very stable materials are used. The following guidelines divided into design guidelines, process control guidelines, test guidelines, and application guidelines will assist the designer in selecting and designing switch applications for dormancy. (Ref 24)

The reader should also consult MIL-STD-1132, Selection and Use of Switches, (Reference 67) and the applicable MIL specs for detailed specifications for the various Military Specification switches.

4.1.7.1.1 Design Guidelines

- Use hermetically sealed, metal enclosed switches. Accomplish the hermetic seal by electron beam welding. Soldering or non-metallic sealers introduce both particulate and gaseous contaminants.

- Use either a metal bellows or metal diaphragm for the seal around the activation mechanism. Do not use an elastomer seal. This metal seal should also be accomplished by electron-beam welding.

- Contacts should be alloys of nickel, silver or palladium for loads greater than 500 milliamperes. For loads less than 500 milliamperes, the contacts should be gold plated to minimize oxide films and maintain low contact resistance.

- The minimum thickness for gold plating is 0.000100 inch. Thinner platings may burn through. Thicker platings are neither necessary nor cost effective.

- External electrical terminals should be sealed with glass with a matched thermal expansion coefficient for strength, dielectric and gas seal qualities.

- Solder hook external contacts are required to provide stress relief to the glass seal. Plug-in units are not recommended because the glass seal may be stressed.

- Getter devices should not be used. They may break or move and interfere with switch operation. Switches must be clean enough without a getter or they are not reliable parts

- Minimize the use of non-metallic materials because they are prone to outgas in low pressure applications, and they are a source of particulate contamination (consult reference 11 for outgassing effects). Non-metallic materials also have lower mechanical strength, are more temperature sensitive, and do not have the long term stability of metals.

4.1.7.1.2 Process Control Guidelines

- Switch assembly should take place in a clean room environment to preclude particulate contamination; which is a major problem encountered with switches in dormant applications.

- The transfer of switch components between assembly stations should be accomplished in sealed plastic bags to reduce contamination.

- Vacuum bake-out of switches should be conducted at 200 degrees C, 1 mm pressure for a minimum of four hours to prevent subsequent contaminating films of non-metallic materials. Some components may require as much as 16 hours, two cycles. One purge cycle with gaseous nitrogen (GN2) is recommended as a minimum.

- The out-gassing hole in the switch enclosure should be sealed in the backfill chamber to prevent contamination.

- The back-fill and bake out chamber should be cleaned after each operation to remove hydrocarbon (oil) condensate from chamber walls.

- During assembly, each mechanism piece should be checked against the installation print for proper installation. A go/no-go test should be made for every clearance specified, with no hindrance of motion.

- Plating of piece parts should be avoided. Where unavoidable, the plating process (temperature, raw material purity, bath cleanliness, voltage stability, etc.) should be continually monitored and controlled. In addition, destructive parts analyses should be conducted on 5% of the piece parts to verify plating adherence, absence of cracks, and the achievement of a fine-grained structure.

- Cleaning baths should be constantly filtered and recirculated with approximately a 20% replacement after each cleaning process.

- Incoming material inspection should be on a sample basis as a minimum and should verify materials, dimensions and tolerances as well as workmanship. Materials should be stored in contamination protected containers or bags.

4.1.7.1.3 Test Guidelines

The reader should consult section 4.5 of this document, "Testability Design", for testability design guidelines for dormant systems. The following design guidelines are presented to insure reliability in switches used in dormant applications.

- Qualification and acceptance (screening) testing should be accomplished using MIL-S-8805 as a minimum. Additional program peculiar requirements should be added as required.

- For acceptance testing of production hardware, the above specifications are inadequate in certain areas and, therefore, must be supplemented with the following inspections and tests.

- Radiographic inspection on 100% of the devices should be accomplished in accordance with more comprehensive inspection criteria, such as MSFC-STD-355 to detect contamination, bent parts, and misaligned parts.

- For switches, an operational run-in (2000 cycles of operation at -65 degrees C, 2000 cycles at +125 degrees C and 500 cycles at +25 degrees C) should be conducted as a 100% screen test. The voltage drop across the contacts should be monitored during cycling and the electrical characteristics after the test.

- Seal tests should be performed on 100% of the devices to verify the seal integrity.

- A sinewave vibration test of 30 g's 52000 Hz should be performed as a 100% screening test with contact resistances monitored during the test to insure the absence of contact chatter and transfer. During vibration, switches should be monitored for a short to case condition.

- Accelerated testing is basically accomplished by the run-in testing described above. However, one variant which should be considered for selective application is the exposure of the nonoperating switch to high temperature followed by operation under a very light load to establish that outgassing of inorganic material has not produced a contamination film on the contacts. This accelerated test approach is aimed at a final verification of the adequacy of the bakeout processes. The reader should consult section 5.0, "Evaluation Methods", to identify more comprehensive evaluation guidelines for dormant systems.

4.1.7.2 Environmental Effects/Guidelines

Many types of enclosures are available to protect switches from external conditions, particularly moisture and contaminants. Such classifications include the following: open, sealed, enclosed, environmentally sealed (resilient), and hermetically sealed. With the open construction switch, no effort is made to protect the switch or its parts from the external environment. This type of switch is not recommended for application in dormant equipment. Degradation of contacts due to storage in severe environments may cause malfunction of equipment when it is required to operated. The enclosed switch is one in which the contacts are enclosed in a closed case made of plastic or metal and plastic. Plastic and metal cores do not create an effective hermetic seal and are subject to degradation from moisture and low pressure, therefore, plastic and metal sealed switches are not recommended for application in dormant equipment that may be subjected to these environments. The environmentally sealed (resilient) switch is in a completely sealed case where any portion of the seal is a resilient material such as a gasket or a seal in the bushing of a panel mounted switch. This type of switch is recommended for application in moist, or sand and dust environments, but the gaskets may be subject to degradation in low pressure applications. The hermetically sealed switch is made airtight by a sealing process which involves fusing or soldering and does not use a gasket. The hermetically sealed enclosure offers the greatest protection against such elements as moisture and other degradative contaminants, and avoids potential outgassing of plastic materials in low pressure applications.

The following lists the major environmental considerations that the designer must consider when selecting a switch for dormant applications:

High Temperature

- Chemical action to which switches are subjected to is accelerated by high temperatures. Insulation resistance between the switch contacts and ground decreases as the temperature increases. In high resistance circuits with 3 megaohms in parallel with a circuit impedance of 1 megaohm, the circuit impedance will change to a point where operational failure of the equipment may occur. High temperature may also affect the insulation from the standpoint of voltage breakdown due to a change in dielectric strength. Also, the increased speed of corrosion of contacts and switching mechanism is affected by high temperature.

Low Temperature

- Exposure to low temperature may cause certain materials of a switch to contract, thus causing cracking, permitting moisture or other foreign contaminants to enter the switch causing potential short circuits, voltage breakdown, or corona.

Moisture

- Moisture in the dielectric will decrease the dielectric strength, life, and insulation resistance and cause corrosion by increasing the galvanic action between dissimilar metals. In general, switches should be hermetically sealed, and/or the use of accessories such as boots, "O" rings, or diaphragms placed over switch openings, is recommended to eliminate moisture entry.

Low Pressure

- With a decrease of pressure, the spacings required to prevent flash-over increase substantially. Small switches, because of their very close contact spacings, are partially susceptible to malfunction at high altitudes. To compensate for increased arcing at high altitudes, users must derate the current rating given by the manufacturer. To compensate for increased flash-over, the user must derate voltage ratings. No problems are anticipated for dormant switches, other than possible outgassing. To mitigate the potential effects of outgassing, the user should avoid switches with non-metallic (organic) components. For more detailed outgassing information, the reader should consult Reference 11.

Shock, Vibration, Acceleration, and Gun Fire

- The primary degradative aspects of acceleration and gun fire for dormant switches is shock and vibration experienced during these environments. Switches should be selected which meet shock and vibration requirements (see applicable MIL specifications). Those switches with specific contact chatter requirements are suitable for application in low frequency and shock environments. High frequency of vibration will determine the effects of fatigue and resonance on the mechanical construction of the switch contact elements. When contact bounce at the time of closing of switch contacts is important, this requirement should be a consideration to be specified.

Temperature Cycling

- Variations of temperature must be considered, as moisture condensation within the switch could develop. In choosing a switch for a wide range of temperature, the entire temperature range must be carefully considered rather than one extreme. To mitigate the effects of moisture condensation switches should be hermetically sealed. If the contacts are in a sealed enclosure, the fill gas should include oxygen. (Ref. 67)

Sand and Dust

- A combination of sand and dust and small amounts of moisture will materially increase the possibility of voltage breakdown of the insulation between closely spaced terminals.

Nuclear Radiation

- Nuclear radiation affects switches primarily by damage to organic insulating materials. Some microswitches suffer damage to the plastic cases and actuators at gamma-ray exposures as low as 4 to 6×10^{8} ergs g^{-1} (C) or integrated neutron fluxes at 10^{15} n cm^{-2} (>0.7 Mev). (Ref 16)

- A secondary problem, induced radioactivity, arises if handling and maintenance of the units are required. This induced radioactivity may constitute a radiation hazard to personnel. (Ref 16)

- Contacts of gold or silver should be avoided, if possible, because they have high neutron-absorption cross sections as compared with aluminum or some tin alloys.

- The major radiation resistance factor for switches is insulation materials. The designer should consult reference 16, Effects of Radiation on Materials and Components, for a detailed examination of insu[illegible]on materials and radiation effects.

4.1.8 Connectors

Connectors come in a wide variety of shapes, sizes, densities, support hardware, electrical and mechanical characteristics, and environment withstanding properties. The reader should refer to MIL-STD-1353 (Ref 70) and the applicable MIL specifications for detailed application and specification information. This section will present guidelines for the selection and control of connectors for dormant applications.

The proper determination by the user of which of the numerous connector types and associated hardware is most suitable for his application is one of the most important contributions to equipment reliability that the designer can make. (Ref 1)

The primary factors affecting the failure rate of connectors are insert material, contact current, number of active contacts, mate/unmate cycling, and the environment in which it is applied. Contact current and active contacts are not considerations during dormant periods, however these aspects must be addressed by the designer to insure reliable operation during the operating period. Designers should consult MIL-STD-1353 and applicable MIL specs to determine operational ratings for contact current and the maximum number of active c[illegible]s for the particular application. The primary failure mechanism connectors during dormant periods arise from mate/unmate cycling and environmental degradation of insulating and contact materials. The remainder of this section presents these failure mechanisms and guidelines to increase the reliability of connectors during these phases.

Achieving good electrical contact in a connector is a function of mechanical degradation, contact surface films (oxides and sulfides), surface roughness, contact area, plastic deformation of the containing materials and load applied. The performance of the connector is dependent upon the chemical, thermal, and the mecha ical behavior at these points.

Mate/unmate cycling is the primary mechanical degradation of connector contacts. The most obvious malfunctions due to cycling are broken contact elements and ineffective contact of these elements. Many connectors, particularly of the cable type that are repeatedly plugged and unplugged during maintenance and testing, continuously expose the contacts to possible corrosive contaminants. These cycling effects also create the problem of physical wear on the connecting interfaces. The result is increased interface resistance, higher contact temperature during operating periods, and degradation of the electrical connection. As a result, mate/unmate cycling increases the failure rate of electrical connectors. Control of maintenance practices will assist in the control of these failure mechanisms. Detailed maintenance guidelines for dormant equipment are presented in section 4.5, "Maintainability Design" of this text.

Environmental factors are the next primary failure mechanisms for dormant connectors. Section 4.1.8.1 presents general design and application guidelines for selection and control of connectors for dormant applications. Section 4.1.8.2 presents environmental effects and guidelines for dormant connectors.

4.1.8.1 Guidelines

To protect unmated dormant connectors from degrading environmental factors, all unmated connectors should be kept covered with moisture proof or vapor proof caps specified by military specifications or military standards and designed for mating with specific connectors. Where such protective caps are not available, disposable plastic or metallic caps designed for this purpose should be used. Plastic and metallic caps, however, are subject to degradation, and should be chosen with these degradations in mind. Metallic caps should be chosen to mitigate the corrosive effects of moisture on metals, and plastic caps are subject to outgassing in low pressure applications. Plastic caps should also be chosen to match the thermal requirements of the connector.

The following are general design guidelines or connectors for dormant applications:

- Whe ver applicable, use gold plating on contacts. The softness and inertness of gold reduces susceptibility to film contamination, which is a major degradation mechanism in dormant connectors.

- The minimum thickness for gold plating is 0.000100 inch. Thinner platings may burn through. Thicker platings are neither necessary nor cost effective.

- If the anticipated operational load is greater than 500 milliamperes, than the contacts should be alloys of nickel, silver, or palladium. Otherwise, gold contacts are recommended.

- Plating processes should be closely monitored. Plating is a major source of particulate contamination.

- Minimize the use of non-metallic materials because they are prone to outgas, are a source of particulate contamination, have a normally lower mechanical strength, are more temperature sensitive, and do not have the the long term stability of metals (instability arises in metallic components, see the low temperature guidelines in the following section).

4.1.8.2 Environmental Effects/Guidelines

Many connector contact failures are induced by the growth of films at points of contact. These films can cause increased contact resistance or open circuit. Ions in impurities or contamination in the surface pores of contacts will migrate to the points of highest potential, which are frequently localized hot spots. Ions interfacing with electrons and other constituents at the points of high chemical activity usually generate nonconducting films. There is also a continuous supply of material for the growth of insulating films from environments where there are corrosive elements such as hydrogen sulfide, moisture, oxygen, ozone, hydrocarbons, and various dusts.

The following presents environmental effects and guidelines to assist the designer in controlling connectors to maintain reliability during dormant periods.

High Temperature

- High temperature can cause failure of connectors by breakdown of insulation or by breakdown in the conductivity of the conductors. Either malfunction can be partial or complete. A typical breakdown caused by excessive temperature occurs progressively. As temperature increases, insulation tends to become more conductive, and, simultaneously, the resistance of conductors increases. Complete failure will occur if the temperature reaches the point where the conductor melts, breaking electrical conductivity, or where the insulation fails, causing a short.

Low Temperature

- Metals and nonmetals tend to become brittle and shrink at different rates. How important each characteristic is depends on the application. Designers should consult the applicable MIL specification for the chosen connector to identify low temperature ratings. The coefficient of expansion of plastics and elastomers are so different from those of the metals used in structural members that they will shrink enough at extremely low temperatures to open seals. An open seal may not cause a malfunction unless moisture and contaminants enter through the opening. If a seal opens after the temperature of a connector falls below the freezing point of the contaminants present and then seals itself before the melting point of the contaminants is reached, foreign matter will never enter. However, if a connector seal opens at a temperature where liquid or gaseous contaminants have not been frozen they can enter and contaminate the connector.

Moisture

- Moisture is a primary degradation mechanism for dormant connectors. Moisture is a corrosion inducing element, and also serves as an adhesion element for other corrosive contaminants.

- Unmated connectors should be protected from moisture by protective metal or plastic end caps. Whenever possible additional moisture protection methods should be applied. For example connectors should be maintained in sealed, moisture free containers or additional protection applied to the external portions of the cap and connectors junction, such as an additional wax type sealant.

- Mated connectors should be contained in sealed moisture free containers to mitigate moisture entry to contact elements.

- Extreme caution should be observed during maintenance and testing to preclude the entrance of moisture during connector mating/unmating cycles to reduce failure mechanisms identified in the previous section.

Low Pressure

- The primary failure mechanism for dormant connectors in low pressure applications is outgassing of organic (nonmetallic) materials. For low pressure applications the connector should be constructed of non-organic (metallic) components to reduce the possibility of outgassing. For more detailed outgassing effects, the designer should consult reference 11.

- During operational periods, connectors intended for use in low pressure applications should be derated to account for the tendency of voltage flashover. This derating is specified in the military specifications for conductors intended for use at other than sea level barometric pressure.

Shock, Vibration, Acceleration, and Gun Fire

- The primary degradative aspects of acceleration and gun fire for dormant connectors is shock and vibration experienced during these environments.

- The primary failure mechanism introduced by shock or vibration is ineffective electrical contact at the connector contacts. For shock and vibration environments, connectors should have positive screw coupling mechanisms and adequate support for the cable or wire bundle.

Temperature Cycling

- Variations of temperature must be considered as moisture condensation within the connector could develop. (See Moisture)

Sand and Dust

- A combination of sand and dust and small amounts of moisture will materially increase the possibility of voltage breakdown of the insulation between closely spaced contacts.

Nuclear Radiation

- Materials frequently used in the manufacture of electrical connectors include: plated copper or bronze alloy for contact pins and receptacles, dielectric materials such as plastics, ceramics, or glass, and outer shells or shields which are usually steel, brass, or aluminum. Since metals are known to undergo relatively small changes in electrical characteristics when exposed to nuclear radiation, limited concern is necessary for metallic connector components. (Ref 16)

- The effects of radiation on the dielectrics of connectors is the main concern. Two types of degradation are encountered, and both deal with the dielectric characteristics of the insulating inserts. Degradations which change the physical characteristic of dielectric materials may also result in mechanical weakness in pin supports and are indicated by the appearance of brittleness in organic type materials. Permanent and/or temporary loss of insulation resistance between contacts or in the outer shell is another form of degradation. (Ref 16) The reader should consult reference 16, Effects of Radiation on Materials an Components, for a more comprehensive presentation of the degradation of insulating materials in radiation environments.

4.1.9 Cables/Wires

Wires and cables are divided into several types based on performance characteristics and on construction details. The most common types are: (Ref. 14)

Wires

- Single conductor, shielded.
- Single conductor, unshielded, high voltage leads.

Cables

- Single conductor wires twisted together, shielded and unshielded.
- Coaxial cables.
- Multiple-conductor round cables.
- Multiple-conductor flat cables.

The reader should consult the applicable MIL specifications for a more comprehensive description of the various wire and cable types. The following sections present the primary degradation mechanisms and guidelines for cables and wires in dormant applications.

Wires and cables are generally subjected to three different primary mechanical stresses depending upon their usage: installed and never moved or flexed, flexed during installation and occasional servicing, and repeated or constant flexing. Cables in dormant applications may be subjected to any or all of these stresses during the equipment life-cycle. Flexed installations require proper stress relief at connectors to prevent breakage. Installations requiring repeated or constant flexing requires engineered cable and harness flexibility, including balanced assembly (or twisting) of wires in the harness to eliminate short lengths and stress relief of all conductors at termination.

There are two predominant failure mechanisms for dormant cables and wires: insulation degradation and conductor breakage. Insulation degradation and possible breakdown can be induced or accelerated by several different environments during the dormant period. It is beyond the scope of this document to present all of the various types of insulation and corresponding failure mechanisms. The following subsection presents some general part selection/control guidelines for cables and wires in dormant applications. The reader should refer to Reference 15, A Review of Equipment Aging Theory and Technology, for a more detailed discussion of the aging mechanisms of specific insulation materials.

Generally conductor breakage is due to mechanical stresses as described above or through additional induced mechanical factors experienced during the equipment life cycle. These environmental factors include shock, vibration, gun fire, and acceleration. Conductor breakage failures can most often be attributed to poor workmanship and poor assembly procedures. Furthermore, the mechanical weakness of conductors sized #24 AWG copper and smaller increases the problem. Wire breakage has been a major problem with small conductors. Overcoming this problem, for both small and large conductors, involves providing proper stress relief of all wires at connectors. (Ref. 14)

4.1.9.1 Environmental Effects/Guidelines

The following presents environmental effects and guidelines to assist the designer in controlling cables/wires to maintain reliability during dormant periods.

High Temperature

- As temperature increase, insulation softens and loses its cut-through resistance. If a thin edge is pressing against it, flow can occur at high temperature until the conductor is exposed and shorting results. (Ref. 14)

- Temperature in excess of the insulation rating will result in insulation degradation (shortening of life) and possible excessive deterioration by flow or carbonization. Insulation aged and hardened by excessive heat may be subject to cracking if flexed. (Ref. 14)

- Avoid the use of polymeric insulators as these tend to deteriorate more rapidly in high temperature environments.

- Thermosetting plastic insulating materials such as phenolics perform better than ABS, polycarbonate, polypropylene, or acetal resins.

Low Temperature

- Temperatures below the insulation rating may result in fracture if the wire or cable is given sharp flexure or impact while it is cold. (Ref. 14)

Moisture

- Moisture can be a primary degradation mechanism for insulation in cables and wires. Resulting moisture penetration is a corrosion inducing element for the cable/wire conductor. Wherever applicable, cables should be kept in enclosed moisture-proof enclosures.

- Use molded cables/wires in preference to bundled wire runs to reduce the area available for moisture and other contaminants.

Low Pressure

- Outgassing of insulation materials (non-organic) is a primary failure mode for cables/wires in low pressure applications. For more detailed outgassing effects the designer should consult reference 11.

- Cables/wires with polyvinyl chloride insulation should not be used in low pressure applications. (Ref. 71)

Shock, Vibration, Acceleration, and Gun Fire

- The primary failure mechanism introduced by shock or vibration is ineffective electrical contact at the cable/wire connector contacts. For shock and vibration environments, connectors should have positive screw coupling mechanisms and adequate support for the cable or wire bundle.

Temperature Cycling

- Temperature variations within the ratings of the cable/wire ratings will generally not affect performance. Variations in temperature must be considered at the connector contacts. Condensation within the connector contact could cause corrosion of the contacts and cable/wire conductor.

Sand and Dust

- A combination of sand and dust and small amounts of moisture entering into the insulation will materially increase the possibility of voltage breakdown of the insulation.

- In humid environments the designer should use molded cables and not bundled wire runs to reduce the area available for moisture, and sand and dust absorption.

Nuclear Radiation

- Metallic conductor materials undergo relatively small changes in electrical characteristics when exposed to nuclear radiation, therefore limited concern is necessary for metallic conductors in cables and wires.

- The effects of radiation of the insulating (nonorganic) materials is a primary concern. Two types of degradation are encountered. Degradations which change the physical characteristics of the insulating materials, and permanent and/or temporary loss of insulation resistance. The reader should consult reference 16, Effects of Radiation on Materials and Components, for a more comprehensive presentation of the degradation of insulating materials in radiation environments.

4.1.10 Batteries

Batteries are divided into two basic groups: primary (non-rechargeable) and secondary (rechargeable). Primary batteries are not electrically recharged easily and are usually discarded once they are discharged. The general advantages of primary batteries are good shelf life, high energy density at low to moderate discharge rates, little or no maintenance, and ease of use. (Ref. 76) Secondary batteries are easily recharged after discharge. Secondary batteries generally have high power density, high discharge rate, flat discharge curves and good low temperature performance. The energy density of secondary batteries is generally lower than the energy density of primary batteries. The charge retention of secondary batteries is poorer than the charge retention of primary batteries, but when the charge of the secondary battery is properly maintained by recharging, it will retain its charge longer than the primary. Generally, for dormant systems the choice between primary or secondary battery systems is the choice between the low maintenance, good shelf life characteristic of the primary battery or the recharge maintenance, superior overall shelf life characteristics of the secondary battery.

Reserve batteries are a type of primary batteries from which an active component is removed from the rest of the battery prior to activation. The active component is usually the electrolyte. Thermal batteries are a type of of reserve battery with a solid electrolyte that melts upon heating. Reserve batteries are intended for long term storage, but the missing component must be added before they can be activated. Generally, reserve batteries do not experience any significant degradation during dormant periods, and they are recommended for dormant applications.

Generally, batteries are a perishable product and deteriorate as a result of chemical actions that proceed during storage. The type of cell design, electrochemical system, temperature, and length of storage are the most significant factors which affect the shelf life of the battery. Low temperature extends the shelf-life of most batteries. However, most refrigerated batteries should be warmed before discharge to obtain maximum capacity.

The primary failure mode for batteries during the dormant period is self discharge. The rate of self discharge of most batteries is increased by high temperature environments. The rate of self discharge for most batteries is reduced in low temperatures. Most batteries should be kept in a cool, dry environment to increase the storage lifetime.

Lithium and Magnesium cell types develop protective coatings on the active material during storage. These films can improve the shelf life of the battery, however, when the battery is placed on discharge after storage, the initial voltage may be low until the film is worn off (Ref. 76)

Figure 4.1.10-1 compares the shelf life characteristics of some of the more popular primary and secondary battery systems. A closer examination of the shelf life characteristics of the major primary battery systems are plotted in Figure 4.1.10-2. These figures present percentage capacity loss per year from 20 to 70 degrees C. The relationship is approximately linear when the log of capacity loss is plotted against the log/temperature (Kelvin). The plots assume that the rate of capacity loss remains constant throughout the storage period, which is not necessarily the case for most battery systems. For most battery systems, the rate of capacity loss tapers off as the storage period is extended, but for purposes of comparison of the shelf life of these battery systems, these figures present a reasonable approximation. (Ref. 76) The reader should refer to reference 76, Handbook of Batteries and Fuel Cells. for a more detailed discussion of these battery systems.

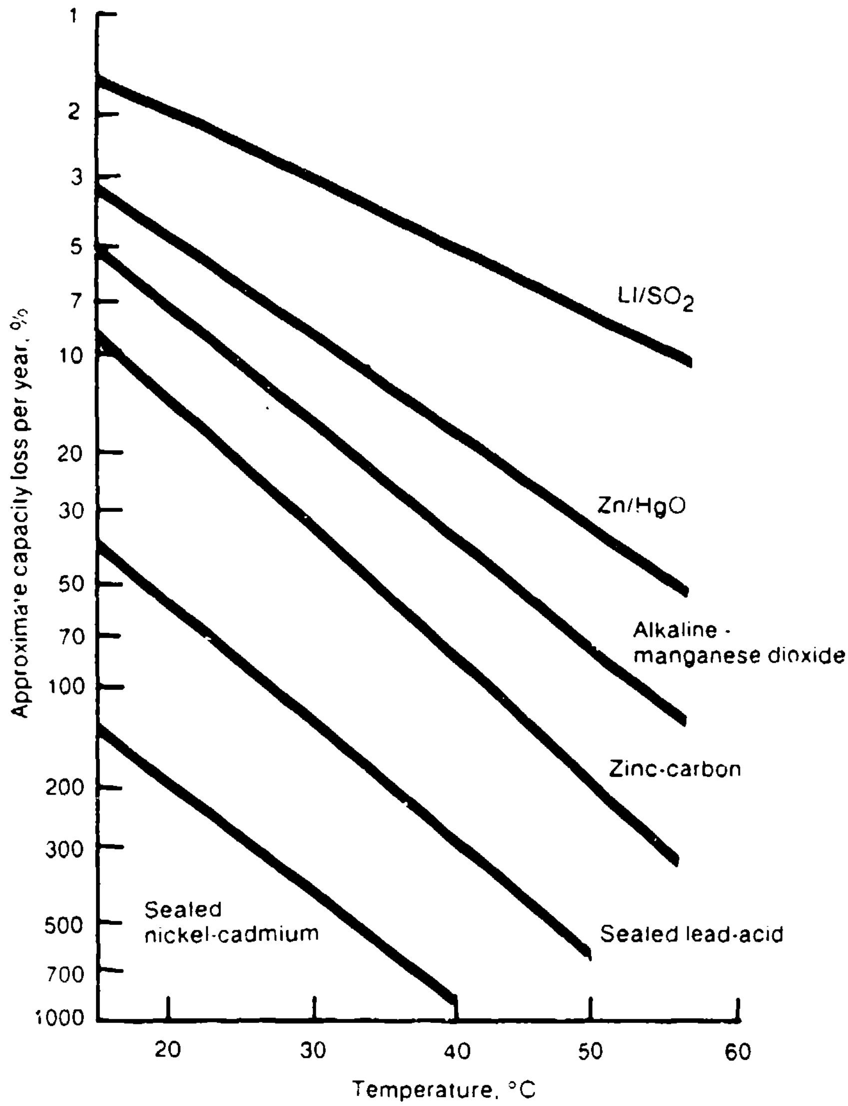

Figure 4.1.10-1. Shelf Life Characteristics of Various Battery Systems (Ref. 76)

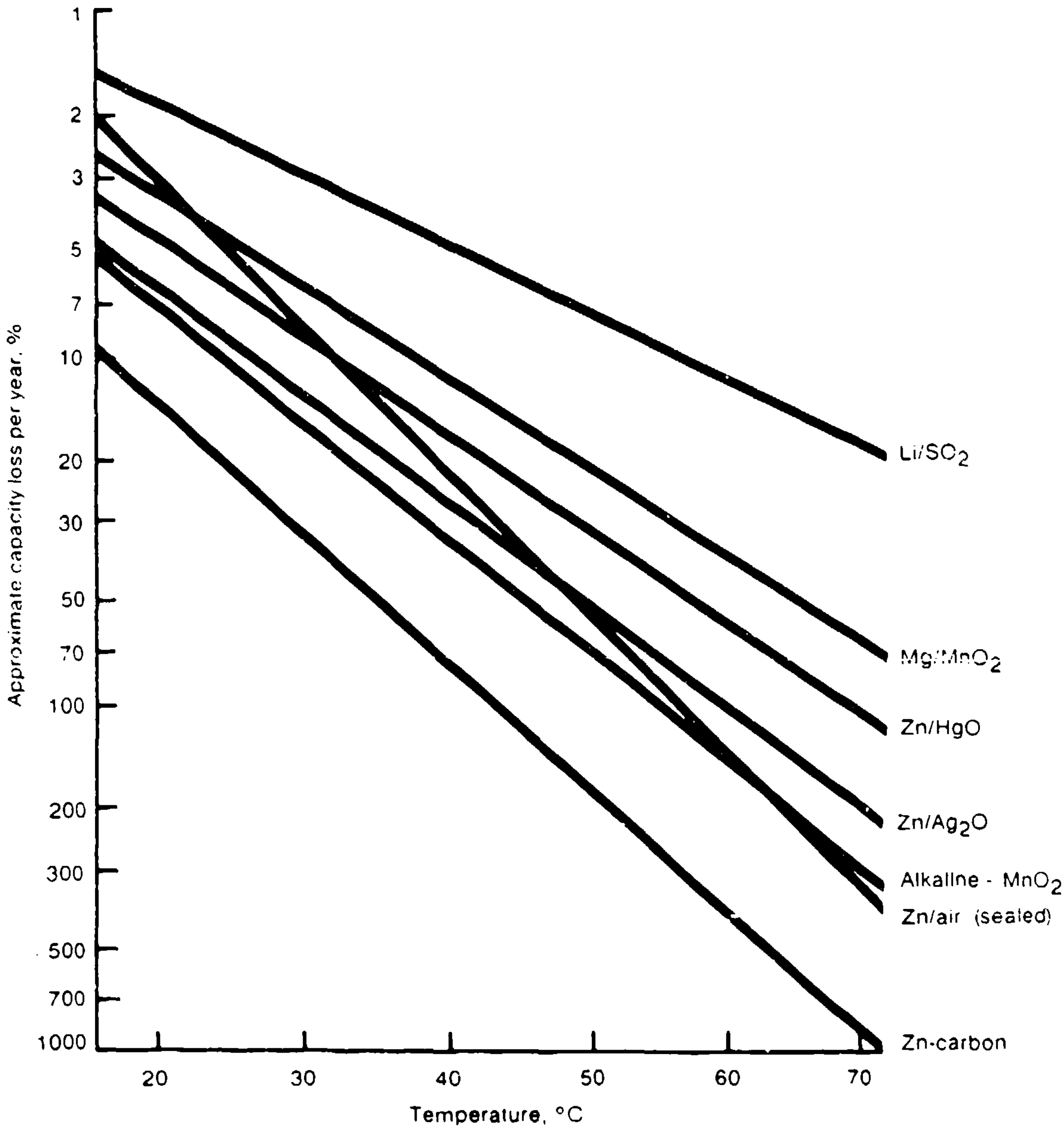

Figure 4.1.10-2. Shelf Life Characteristics of Primary Battery Systems (Ref. 76)

Table 4.1.10-1 presents the characteristics of the most common primary battery systems, maximum storage temperatures, as well as, advantages, disadvantages, and dormancy guidelines for the battery type. Table 4.1.10-2 presents corresponding information for the major secondary battery types.

The following subsections present general guidelines to aid the designer in insuring long term reliability during the dormant period. The guidelines are divided into design, process control, and test guidelines. (Ref. 24)

4.1.10.1 Design Guidelines

- Design excess capacity into the battery to reduce the percent depth of discharge and compensate for capacity decrease with usage. The tradeoff is cost and watt-hours/pound.

- Hermetically seal batteries to avoid degradation as a result of possible electrolyte leakage during the dormant periods.

- For battery types where explosion is a possibility, employ a pressure relief valve to prevent personnel injury and equipment damage as a result of overpressure.

4.1.10.2 Process Control Guidelines

- Employ clean areas during processing and manufacturing to reduce the amount of harmful contaminants. Also, use clean lint-free cotton gloves when handling components. Store components in clean plastic bags when not being processed.

- Employ clean processes, remove the carbonates and keep the nitrates content down to prevent gas pockets that pop off active material.

- Flush and brush plates prior to installation to remove contaminants.

- Control the brazing temperature-time relationship to prevent excess dwell during brazing operations that can cause active material penetration of ceramic seals.

- Avoid rapid cooling after brazing to prevent cracked ceramics and brazing voids.

- Require process and test controls for each active element: plates, separators, and electrolyte to reduce end product variability.

Table 4.1.10-1. Characteristics of Primary Batteries

Battery System, Applicable MIL Numbers, Maximum Storage Temps.	Advantages	Disadvantages	Guidelines
Carbon-Zinc MIL-B-18 -40 to 45°C	-Low cost	-Low energy density -Comparatively low shelf life -Inoperative below -20°C -Rapid deterioration at 50°C	Not recommended for long term dormant storage especially at high temperatures
Magnesium MIL-B-55252 -40 to 70°C	-Good capacity retention even under high temperature storage	-Loses its excellent storage characteristics after being partially discharged	-Not recommended for long term intermittent use -Can be stored for 5 years at 20°C with only 10-20% capacity loss
Alkaline - Magnese-Dioxide MIL-B-55252 -40 to 50°C	-Good shelf life -Operates at temperatures as low as -40°C -High capacity retention	Moderate cost	-90 to 85% capacity retention after 1 year of storage at 20°C -10 to 20% capacity losses after 3 years of storage at 20°C -20% capacity loss
Mercuric Oxide MIL-B-18 -20 to 55°C	-Excellent storage characteristics even under high temperature storage conditions -Capacity loss of 10 to 20% after 2 years at 20°C -Capacity loss c 20% after 1 yr. at 45°C	Expensive	Storability also depends on the discharge load placed on the cell. Failure in storage is usually due to the breakdown of cellulosic compounds within the cell, which at first results in a reduction of the limiting current density at the anode. Further breakdown produces low drain internal electrical loss paths and loss of capacity due due to self discharge. Eventually, complete self discharge can occur, but these processes at 20°C and below take many years. -After long periods of storage the cell electrolyte tends to seep out of the seal and is evidenced by a white carbonate deposit at the seal insulation.

Table 4.1.10-1. Characteristics of Primary Batteries (Continued)

Battery System, Applicable MIL Numbers, Maximum Storage Temps.	Advantages	Disadvantages	Guidelines
			-Cells should be adequately packaged and not stacked up to high to prevent damage, because Mercury cells are heavy. -Should be stored in a relative humidity less than 65%. -Severe shock and vibration could damage the cell.
Silver-Oxide MIL-B-82117 -40 to 60°C	-High energy density -High temperatures accelerate capacity deterioration -Good low temperature performance	Use limited to button and miniature cells because of high cost	
Zinc/Air -20 to 40°C	-High energy density -Long storage life if sealed	-Periodic maintenance required -Susceptible to drying out of cells	-Periodic inspection and maintenance of water level to achieve proper electrolyte level. The use of transparent cases allows visual inspection and simplified maintenance. -During storage the air access holes of the cell should be sealed to prevent gas transfer decay (the access holes must be open when in operation, oxygen from the cell's exterior is one of the reactants).

Table 4.1.10-1. Characteristics of Primary Batteries (Continued)

Battery System, Applicable MIL Numbers, Maximum Storage Temps.	Advantages	Disadvantages	Guidelines
			-Elevated temperatures dramatically increase self discharge rates. -Storage life at high temperatures can be optimized through trade-offs between other performance parameters and choice of cell design components.
Lithium Cells -55 to 70°C	-High energy density -Best low temperature performance -Can be stored for long periods even at elevated temperatures -Effective storage for 10 years at 20°C is projected -1 year at 70°C with little capacity loss -Hermetically sealed, and protected during storage by the formation of film on the anode. This film may create voltage delays after long storage.	-Voltage delays after storage	-Design should be able to withstand short voltage delays after activation of long term storage

Table 4.1.10-1. Characteristics of Primary Batteries (Continued)

Battery System, Applicable MIL Numbers, Maximum Storage Temps.	Advantages	Disadvantages	Guidelines
Solid Electrolyte Lithium -40 to 60°C	-No loss of capacity after 4 years of storage at 20°C -No loss of capacity after 1 year at 60°C -Good low temperature performance	Only available in small sizes -High cost	

Table 4.1.10-2 Characteristics of Secondary Batteries

Battery System	Applicable MIL Numbers	Maximum Temps.	Advantages	Disadvantages	Guidelines
Lead-Acid -SLI -Traction -Stationary -Portable	MIL-B-11188 MIL-B-15072 MIL-B-83769 W-B-134 DoD-B-15072	 -40 to 55°C -20 to 40°C -10 to 40°C -40 to 60°C	-Good high and low temperature operations	-Long term storage in discharged condition can lead to irreversible polarization of electrodes -At 70°C this cell can only be stored for 30 days without re charge	-Charge must be maintained in long term storage -Performance characteristics can be greatly improved and stabilized by removing the electrolyte -Each cell should not be allowed to discharge below 1.8V
Nickel-Cadmium -Vented-Pocket Plate -Vented Sintered Plate -Sealed	MIL-STD-1578 MIL-B-81757 MIL-B-49436 MIL-B-23272 DoD-B-8565 MIL-B-55130 MIL-B-26022	 -20 to 45°C -40 to 50°C -44 to 45°C	-Can be stored for long periods of time without recharge -Can be stored over a broad temperature range	-Low energy density	-Best practice is to store in an upright position at a temperature range from 0° to 30°C
Nickel Zinc		-20 to 60°	-High energy density -Good low temperature perform ance	-Poor cycle life	-Should be stored in a well ventilated area to prevent the accumulation of potentially explosive Hydrogen
Zinc/Silver Oxide	MIL-B-82117 MIL-B-29361 MIL-B-11814 DoD-B-24506 DoD-B-24531	-20 to 60°C	-High energy density -Low self discharge	-Short cycle life -Can provide extremely tremely high currents if shorted	

Table 4.1.10-2 Characteristics of Secondary Batteries (Continued)

Battery System	Applicable MIL Numbers	Maximum Temps.	Advantages	Disadvantages	Guidelines
				-Electrolyte is extremely caustic solution of Potassium Hydroxide	
Nickel-Hydrogen		0 to 50°C	-Long cycle life, even on deep discharging -High energy density	-Self discharge in 100 hours at ambient temperature	
Rechargeable "Primary Types" (Magnesium, Silver Oxide)		-20°C to 40°C	-Good shelf life -Good capacity retention -Completely sealed and maintenance free	-Useful capacity is only 1/3 of primary versions -Small sizes only	-Available energy rapidly with cycling

4.1.10.3 Test Guidelines

- Helium leak check test the assembled cells.

- Wherever applicable, subject battery during acceptance test to a minimum of three charge/discharge cycles, high impedance short test, and leakage tests. These tests should provide assurance that the basic operating characteristics and construction are satisfactory.

- X-ray along three axes to find gross battery defects.

- Conduct a minimum of 30 charge/discharge cycles on assembled cells to minimize infant mortality and to confirm the matching of individual cells. Resident inspection should observe and confirm these tests.

4.1.11 Fiber Optic Components

This section addresses the reliability of fiber optic cables in dormant applications. Fiber optic connectors are similar in function to standard connectors, and the guidelines presented in section 4.1.9 are also applicable to dormant fiber optic connectors.

Fiber optics is a relatively new technology and the amount of failure data available for dormant fiber optic devices is limited. The following section presents general guidelines for the selection and control of fiber optic devices in dormant applications. This section addresses glass optical fibers, both single and multimode. Fiber optic connectors, splices, taps, and pigtails are also addressed.

Glass in its various forms and material compositions was developed thousands of years ago. It has proven to be one of the most durable and strongest substances known. It has been stated that glass can last forever if it remains mechanically unstressed and in the absence of moisture. (Ref. 80)

Optical fibers are dielectric wave guides relying on total internal reflections in which light is reflected from a refractive index discontinuity within the fiber. Failures in optical waveguides, connectors, and splices can be inherent or induced. Induced failures may be due to externally applied shock, vibration, temperature extremes or cycling, radiation or other stimuli resulting from accidents or maintenance action. The durability and strength of glass suggest that most fiber failures are induced. (Ref. 80)

The absence of yield causes glass to be brittle and unable to withstand heavy shocks. However, glass also can develop inherent failures. An example is crack growth, where dominant flaws can increase in size under induced stress until fracture occurs. (Ref. 80)

A variety of materials are used for optical fibers. The most commonly used is ultra-pure fused silica (SiO_2). This is produced by a chemical vapor deposition process, usually through the collection of SiO_2 soot obtained by the combustion of silane (SiH_4) or silicon tetrachloride ($SiCl_4$). Selected doping elements or compounds are added to the process to control index. The resulting fibers combine extremely high physical strength with optical transparency. The absence or scarcity of impurities reduces the probability of heterogeneous grain boundaries where flaws and weaknesses are likely to occur, and reduces Rayleigh scattering in the optical path. (Ref. 80)

Typical dopants used are metal oxides, sulfides, or selenides. Because they are fused mixtures, rather than fixed compounds with crystalline structures, their compositions are infinitely variable and large numbers of different mixes can be manufactured. The need for low optical losses, i.e., high chemical purity has led to the development of glasses which can be prepared directly from the vapor phase. Small amounts of dopants are introduced into the gas stream to modify the refractive index of the material so produced. (Ref. 80)

Since the main and almost sole catastrophic failure mode for fibers is fracture, strength is surely the most important factor affecting long term optical cable reliability. The maximum tensile strength for ultra-pure fused silica fibers, as used in fiber optical applications, may be as high as 2×10^6 lb/in ^{2} making this commodity one of the strongest materials known. However, brittleness, or lack of yield, has made this material vulnerable to shock, vibration, rough handling and other such applied stresses. To overcome some of the difficulty, it has become necessary to coat the fibers individually to protect them from mechanical damage and to preserve their high inherent strength. Coating used may be epoxy-acrylate or urethane-acrylate, both of which are extremely strong plastics. (Ref. 80)

Besides brittlenesses, glass exhibits delayed failure or "static fatigue", and a wide variability in fracture strength. Static fatigue is a property which causes a fiber to break when exposed to constant stress over long time periods. The fracture strength variability greatly contributes to difficulties encountered when attempting to predict reliability or useful life of fibers and cables. (Ref. 80)

Connectors, installed at cable ends, facilitate quick removal and replacement of fiber optics components, assemblies, or units. Occasionally, connectors must be uncoupled for service, maintenance, interchange of equipment or for reasons of mobility. During an uncoupling-recoupling cycle, the fiber ends within a connector are exposed to the immediate surroundings. If these include dust, sand, dirt, or moisture, connector failures are possible. The failure may be catastrophic if fracture has occurred or recoverable if effective cleaning is possible. (Ref. 80)

The reliability of splices depends upon chemical and physical stability of the materials involved. Reliability also depends upon the care taken during splicing procedures. In addition, light transmission losses occur as a result of misalignment or differences in core diameters and geometry. (Ref. 80)

A fiber may be tapped for beam splitting or other reasons. These are usually accomplished by grinding two fibers at designated spots until the two cores are exposed. Then, they are cemented together or welded. Precautions are necessary similar to those for splices. (Ref. 80)

Pigtails are attached to fiber optic components such as light sources or photosensors to allow input or output from these components to be applied to connectors and fibers. Protection is mainly provided by the device enclosures. However, when these devices are opened for servicing or other reasons, the pigtails then become vulnerable to damage. This has proved to be one of the major failure modes of fiber optics systems.

Generally, fiber optic components are very reliable devices in dormant applications. Optical fibers are designed so that inherent mechanical strength is sufficient to withstand heavy vehicles running over them without causing damage. This is true if the ground surface is paved and reasonably smooth. It is not true if the ground is uneven or soft. (Ref. 80)

Some difficulties have been experienced with dust and other contaminants accumulating inside connector assemblies. Cleaning will restore the system to full operational condition. (Ref. 80)

The following presents some guidelines for the protection of dormant fiber optic components from the primary degrading environmental factors. Other than the induced factors described above, the following are the primary degradative environments.

Temperature

Glass optical fibers are generally not particularly sensitive to temperature variations. However, due to differences in linear thermal expansion coefficients among the various materials making up fiber optic cables, temperature variations and cycling can cause compressive and tensile strain to the fibers. Aside from the probability of fracture, losses in signal can also occur due to microbending, that is, microscopic rippling of the fiber, where the signal is partially reflected and some of it is lost in the cladding and fiber coating. These losses do not always constitute permanent failure modes. A return to "normal" temperatures can often effect complete or nearly complete recovery; that is, unless fracture has occurred. (Ref. 80)

Extended exposures may cause gradual degradations or irreversible change in system insertion loss with time and with succeeding temperature cycles. The losses, thus induced, are a function of microscopic roughness in the core-cladding interface. (Ref. 80)

A technique for screening fiber optic cable for fracture strength has been proposed by C. Veraa (Ref. 80). According to this technique examination of sample fiber optical surfaces, using an electron microscope, can aid in determining the size and nature of flaws responsible for the fracture failure mechanism. The relation between flaw size and tensile stress required for fracture has been mathematically demonstrated by Olshansky and Maurer (Ref. 81). By screening samples of fiber optic cable with an electron microscope and determining average flaw size, one could theoretically determine the tensile stress due to thermal cycling or thermal shock at which the fiber optic cable would fracture. Using this technique as a quality control tool, however, would be difficult and costly.

In practice when selecting fiber cable for a dormant application in an environment where thermal cycling and/or thermal shock are expected factors the designer should use simpler techniques to assure the product quality. In particular samples of the fiber optic cable procured should be tested to Methods No. 4010 and 4020 of DoD-STD-1678. (Ref. 81)

Moisture

It is known that water has an adverse effect upon the strength of glass. The presence of moisture reduces the surface energy so as to accelerate strength corrosion or fatigue with time. With no moisture present glass would not fatigue and will theoretically last forever. In practice, however, some moisture is always present. Selecting fiber coating materials which resists moisture is necessary to protect the fibers from this source of deterioration. It is also recommended that molded cables be used in preference to bundled wire runs. This reduces the area available for moisture and other contaminant absorption. (Ref. 80)

Shock and Vibration

Severe vibration or mechanical shock can cause fiber fracture. Fiber fracture can cause dispersion of the energy being transmitted through the fiber, and this can result in loss of function of the fiber.

Vibration and acoustical energy exposure can induce bending losses in fibers. This effect is intensified in the case where fibers are used in a curved position. (Ref. 80)

There are no types of optical fiber which are known to be less susceptible to vibration effects than other types, and part selections can not be used as a means to lessen vibration susceptibility. It is recommended that when designing with fiber optic devices for use in high vibration environments, the system should be designed to avoid sharp bends in the fiber cables. Any form of isolating/vibration absorbing packing placed around the fiber optic cables would also be helpful in lessening vibration damages.

Nuclear Radiation

Neutron and total dose ionizing gamma radiation can effect the performance of fiber optic cable. The effects are primarily manifested by an increase in attenuation. The neutron radiation actually damages the glass structure causing flaws and thus attenuation. The total dose gamma radiation reduces the transmitivity of the optic fiber and produces attenuation.

In using optic fibers in applications where a nuclear radiation environment is expected to be a dominant factor it is recommended that the system be over-designed since shielding the fiber from neutrons and gamma rays is impractical. The cable should be selected to allow for an 80% attenuation loss of system function.

4.1.12 Quartz Crystals

Crystal units are generally made up of a quartz crystal mounted in a metallic holder. The size of the crystal is inversely proportional to the frequency of operation. The crystal unit may also contain a heating element which will help stabilize the crystal temperature. (Ref. 35)

The five important parameters of the crystal unit are: frequency range, mode of oscillation, temperature range, load capacitance, and driving level. The principal stress parameters are the driving power and temperature. However, dormant crystals are not degraded significantly by them.

The frequency and frequency stability of a crystal is sensitive to high levels of moisture and temperature. Crystals should be chosen so that its operating temperatures are well within the specified operating temperature ranges. Proper selection for operating temperatures will also insure proper temperature ranges for dormant periods. In high humidity, metallic cases of the crystal units are subject to corrosion and should be suitably protected. Metallic crystal holders and cases are susceptible to corrosion in a salt-fog environment and should be maintained and suitably protected within sealed enclosures. Crystal cases should be glass sealed to protect the crystal unit in a humid or salt fog environment. Frequency shifts will result from the degredation induced by these environments.

Environments of shock and vibration can damage the fragile crystal unit and lower the frequency of operation of the larger types. (Ref. 86) Consult the appropriate crystal specifications for the recommended safe limits of shock and vibration. (Ref. 35)

Crystal units are also susceptible to frequency shift in an acceleration environment. Designs that contain crystal units that experience acceleration should allow for a frequency shift as per MIL specification requirements.

Nuclear radiation may effect the frequency and frequency stability of crystal units. Nuclear radiation effects can be reduced by selection of the proper crystal types based on manufacturing techniques. Susceptibility of crystal performance to nuclear radiation is ranked from least to most susceptible as follows:

- Swept synthetic crystal oscillators
- Synthetic quartz crystals
- Natural quartz crystals.

Natural quartz crystals are not recommended for application in nuclear radiation environments. High frequency crystal units of any type are more susceptible to nuclear radiation than low frequency units.

While not normally considered electrostatic sensitive devices, most crystal units are susceptible to electrostatic discharges greater than 4000 volts. This level of electrostatic voltage can be induced by improper handling. The damage often results in degradation rather than failure. Utilization of suitable handling implements and materials can help minimize this problem. For example, use of cotton gloves, static eliminator devices, humidifiers, and operator and work bench grounding systems can reduce static buildup during handling. Means of alleviating static problems during shipment include elimination of loose packaging of crystal units and use of metal foil and anti-static (party conducting) plastic packaging materials. The designer should consult DoD-STD-1686 and DoD-HDBK-263 for more detailed guidelines for the handling of devices to mitigate damage from electrostatic discharge.

4.1.13 Electromechanical Devices

Electromechanical devices addressed in this section are motors, blowers, fans, and solenoids. Electromechanical devices, generally produce a mechanical output for an electrical input. Motors, blowers, and fans are electromechanical devices that rotate in response to an electrical input.

The principal stress factors for electromechanical devices are mechanical load, winding temperature, and ambient temperature of operation. Mechanical load is a factor encountered during operational periods, and it is not a degradation mechanism during the dormant periods. Winding temperature is generally higher during operational periods due to temperature increases induced by electrical and mechanical resistance.

Temperature is considered to be the primary factor for determining the life and efficiency of electromechanical devices. Although, high temperatures induced during operation are the primary degradation mechanism for electromechanical devices, surrounding natural environmental temperatures need to be addressed during periods of operation as well as during dormancy. During operation as well as dormancy, high temperature will cause the winding insulation to fail. Low temperatures will cause the bearings to fail, and low temperature will also cause slowed mechanical reaction to applied electrical stimulus. Readers should consult applicable Military specifications for temperature ratings.

As with other electrical devices presented in this section, moisture and contaminants are the primary degradative environmental factors for electromechanical devices during the dormant period. Moisture induced failure mechanisms include: corrosion, insulation breakdown, and low resistance to electrical leakage. Moisture and contaminants are particularly degradative to electromechanical devices, because these devices are generally not hermetically sealed. In order to mitigate the effects of these environments during the dormant as well as subsequent operational periods, electromechanical devices should be maintained in enclosed, protected enclosures. The designer should refer to section 4.5 of this text for more comprehensive packaging guidelines to reduce moisture entry.

Temperature cycling, during dormant periods may produce moisture condensation on sensitive portions of electromechanical devices. Sand and dust, and other contaminants can cause reduced mechanical and electrical efficiency in electromechanical devices. These contaminants also serve as moisture traps, and in conjunction with the moisture, they may promote accelerated corrosion. Dormant devices should be protected from these environments, it is recommended that hermetically sealed units be used whenever possible. Non-hermetic units should be sealed in in a protective enclosure that still allows sufficient heat dissipation when the device is called to operation.

Interior and exterior portions of electromechanical devices are prone to accelerated degradation and corrosion in salt fog environments. Electromechanical devices in salt fog environments should be maintained in sealed enclosures and they should also be plated or painted with a protective coating. These coatings should be periodically inspected and maintained to insure a protective seal. Plating, painting, and packaging guidelines that will inhibit corrosion are presented in section 4.5 of this tert.

Some other failure mechanisms that are of primary concern during the dormant period are: lubrication (drying and oxidation are chief concerns, low temperature annealing of rotating surfaces, and corrosion of surfaces). Other failure mechanisms include swelling, cracking and general material degradation of O-rings, packing and insulators. Corrosion of bearing, contacts, switch parts, gear assemblies and motor are also possible. (Ref 93)

4.2 DERATING

Derating for electrical, mechanical, and electromechanical parts was appropriately defined by Brummett, Cross, Davis, and Towns (Ref. 35) an "the practice of reducing electrical, mechanical, or environmental stresses below the maximum levels that the part is capable of sustaining in order to increase application reliability." In a more general definition, R. T. Anderson stated that (Ref. 2) "Derating can be defined as the operation of a part at less severe stresses than those for which it is rated. In practice, derating can be accomplished by either reducing stresses or by increasing the strength of the part. Selecting a part of greater strength is usually the most practical approach."

Derating cannot be used to compensate for using parts of a lower quality than necessary to meet usage reliability requirements. The quality level of a part has a direct effect on the predicted failure rate. (Ref 92)

Electrical testing of all parts in a lot is not guaranteed for commercial or JAN level military parts. For high reliability applications, only fully tested and screened parts/(including burn-in) should be used in addition to applying the appropriate derating levels. (Ref. 92) The designer should refer to sections 4.4 and 5.0 for more comprehensive test, screening, and evaluation guidelines for dormant systems.

In this study dormant systems have been defined as systems that experience a significant portion of their service life with zero electrical stress. From this definition of dormancy, it is apparent that reducing electrical stress will not directly increase the reliability of dormant systems during the nonoperating period. However, derating of electrical stress will indirectly increase the reliability of dormant systems by reducing operating failures and thus increasing the operational readiness and availability of dormant systems. Although dormant systems spend a significant portion of their life cycle in non-operating states, it is recommended that electrical stress levels be derated by operating load criteria in order to preclude over stress failure during operation periods.

It is beyond the scope and purpose of this document to derive or present operational derating criteria for electrical stress, especially when several excellent references are available. For more detailed operational stress derating guidelines the reader should consult Reference 35, "Reliability Parts Derating Guidelines", or Reference 92, "Reliability Derating Procedures".

In a similar adaptation, dormant systems generally experience less severe mechanical stresses than those encountered by operating systems. The two primary mechanical stresses encountered during non-operating periods (inertial forces and thermal-mechanical interactions, see section 4.1) are generally the result of induced environmental stresses. For example, inertial forces are usually introduced by shock and vibration encountered during transportation and handling. As a result, it is concluded that the primary stress encountered during dormant periods is environmental stress.

Several previous studies have concluded that the failure modes encountered during dormant (non-operating) periods are generally the same as those encountered during operating periods. A Martin-Marietta study (Refs. 7 & 20) provided the following breakout of electronic part non-operating failure modes:

Bonding/Welding	21.5%
Photoetching	17.2%
Transportation and Handling	12.9%
Seal Aging	12.9%
Expansion Coefficient	12.9%
Conductive Cement	8.6%
Defective Hermetic Seals	4.3%
Plating	4.3%
Soldering	4.3%

These failure modes are directly attributable to inadequate manufacturing processes, improper part selection and control, and ineffective part screening. For some components the failure mechanisms are independent of the application environment and for others, it may be time-related and environment dependent. Reduction of environmental stresses is a means of mitigating or decelerating many of the above failure mechanisms.

The rate of deterioration of dormant electronic systems is, for the most part, dependent upon environmental conditions, either natural or induced. Section 3 of this text presents information and general guidelines for the most significant environments encountered during the dormant period.

Each environmental factor makes its own contribution to the deterioration of dormant systems, and the designer must realize that these environments rarely occur singly. Often it is the combination of factors which determine the severity and rate of deterioration. Many materials experience small to moderate deterioration when subjected to only a single environmental factor, but these same materials may be seriously affected by combinations of environmental influences. From this discussion it is apparent that reducing or derating environmental stresses is a means of preventing failure during the dormant period.

Reference 50, "Deterioration of Materials and Recommended Storage Conditions", presents guidelines for environmental factors encountered during storage. This text also presents recommended storage conditions. The recommended storage conditions provide for a reduction in environmental stresses, however, derating factors for these environmental stress are not presented or discussed.

Controlling or reducing the environmental stresses for dormant systems can amount to a significant cost, even for the control of a single environmental stress. This presents a cost tradeoff decision of choosing reduced dormant reliability , with less stringent environmental control, and less cost, or increased dormant reliability, environmental control measures, and respective increased cost. Packaging, and Transportation and Handling guidelines for dormant systems are presented in sections 4.5 and 4.6 of this test, respectively. Part Selection and Control guidelines are presented in section 4.1. These guidelines are presented to aid the designer in designing a reliable design for dormant applications. For derating purposes, the guidelines can be expanded allow to for an even greater reduction of environmental stresses during the dormant period.

An alternative solution to environmental stress derating is suggested by Anderson's definition of derating, which could also be defined as a policy of overrating. In his definition Anderson suggests that selecting a part of greater strength than required is usually the most practical means of establishing reduced stresses. This derating criteria presents a cost-effective and practical approach to establishing an overall derating policy for dormant devices.

An overall approach for establishing a derating policy for dormant systems should include operation derating guidelines, environmental stress derating guidelines, and overrating policy for part selection for anticipated stresses. A combination of these derating criteria, in conjunction with an effective part selection/control, packaging, and transportation and handling program based upon anticipated dormancy environments should provide a cost effective reliability program for dormant design.

4.3 MAINTAINABILITY DESIGN

All equipment should be subject to an appropriate maintainability program in accordance with MIL-STD-470 (Ref. 73). Equipment maintenance is a prime driver of equipment life cycle costs (LLC) and a major determinant of equipment availability. All equipment, regardless of the amount of its service life that will be spent in a non-operating state, must be designed to an appropriate maintenance philosophy that achieves reliability and availability requirements and minimizes life cycle costs. The following sections provide maintainability design guidance for systems that will spend a significant part of their service lives in non-operating states. Maintenance concepts for dormant equipment are first discussed in section 4.3.1. Maintainability design considerations for these maintenance concepts are then discussed in section 4.3.2.

4.3.1 Maintenance Concepts for Dormant Equipment

The selection of a maintenance concept for a given system design depends upon the nature and characteristics of the given system. For some systems, (e.g. orbiting satellites) maintenance is difficult or impractical. For other systems (e.g. missile systems) maintenance concepts specifying regular, periodic servicing periods are often prescribed.

The development of the maintenance concept is the central activity of maintenance support planning. The maintenance concept defines criteria for maintenance activities and resources allowable at each of the specified maintenance levels. It is derived from the operational and ILS concepts of the system and from the policy statements which form the constraints and boundaries of the support system as expressed in requirements documents. The maintenance concept serves two purposes: (Ref. 74)

(1) It provides the basis for the establishment of maintainability design requirements.

(2) It provides the basis for the establishment of maintenance support requirements in terms of tasks to be performed, frequency of maintenance, preventive and corrective maintenance downtimes, personnel numbers and skill levels, test and support equipment, tools, repair parts, facilities, and information.

The maintenance concept must be both realistic and sufficiently definitive to meet the needs of the system/design engineers and the requirements of logistic support planners. Since the primary purpose for which a system is acquired is intimately related to some set of missions, analysis of the implications of maintenance policies on system design starts logically with mission and operational requirements. The maintenance concept is concerned with policies and goals pertaining to: (Ref. 74)

(1) Operational states of the system.

(2) Maintenance activities.

(3) Maintenance and support resources.

(4) System effectiveness.

These categories are further subdivided as shown in Table 4.3.1-1.

Over the years, two maintenance concepts have developed for equipment that will spend a significant part of its service life in a non-operating state. They are the no-maintenance or "wooden round" maintenance concept and the periodic monitoring/repair maintenance concept. These two concepts are discussed in sections 4.3.1.1 and 4.3.1.2 respectively.

4.3.1.1 "Wooden Round" Maintenance Concept

The "wooden round" maintenance concept is essentially maintenance-free storage of equipment through the elimination of organizational level preventive maintenance throughout the storage period. There are two types of wooden round maintenance concepts:

- Total wooden round which eliminates the need for organizational level maintenance and uses maintenance-free storage for the storage life of the system.

- Quasiwooden round which uses limited on-condition maintenance at long intervals (5 years or more), carried out by contractor personnel using commercial test equipment, special tooling, commercial documentation, and spare parts (if required).

Systems that are used intermittently or only once (such as a missile or munition), or are not economically repairable once they fail (such as inexpensive hand-held calculators) are good candidates for the wooden round maintenance concept. Design considerations for the wooden round maintenance concept are discussed in section 4.3.2.1.

Table 4.3.1-1 Classification of Maintenance Policies and Goals

A. OPERATIONAL STATES

1. Non-operating (Dormant) Period
2. Scheduled Downtime Period
3. Operational Demand Period
   a. Standby
   b. Alert
   c. Reaction
   d. Mission
   e. Deactivation

B. MAINTENANCE ACTIVITIES

1. Preventive Maintenance
   a. Service
   b. Inspection/Test
2. Corrective Maintenance
   a. Detection
   b. Diagnosis
   c. Correction
   d. Verification
3. Maintenance Level

C. RESOURCES

1. Personnel
   a. Operators
   b. Maintenance Technicians
2. Equipment
   a. Prime
   b. Support
3. Facilities
4. Repair Parts and Supplies
5. Information (Publications and Data)

D. EFFECTIVENESS

1. Downtime
   a. Detection Time
   b. Diagnostic Time
   c. Correction Time
   d. Verification Time
2. Reliability
3. Availability or Operational Readiness
4. Dependability
5. Mission Completion Success Probability (MCSP)

4.3.1.2 Periodic Monitoring/Repair Maintenance Concept

The periodic monitoring/repair maintenance concept is shown in figure 4.3.1.2-1. It consists of fixed calender inspection limits, operating times, checks, and overhaul of equipment. To carry out these measures, it is necessary to remove equipment and assemblies from the dormant systems and subject them to preventive and corrective maintenance procedures in order to maintain their reliability and operational readiness states.

This maintenance concept was often employed on first-generation missile systems. This required these systems to be designed to meet test environments (that is, they had to be designed to be capable of withstanding testing for hours); whereas, the real operating time was often only a few minutes. The frequent handling and testing of these systems was found to cause many failures. According to a Redstone Arsenal study (Ref. 18), as many as 50 percent of confidence test rejected missiles were erroneously faulted or were found to contain test-induced failures. These first generation missiles were often tested to failure and overhauled to death.

As a result of these experiences and findings, inspection intervals for equipment have been enlarged and often multiplied without any reduction in reliability. In fact, by drastically reducing the testing, reliability is seen to improve, and, in many cases, it has been possible to entirely eliminate the periodic checks. (Refs. 7, 75)

Design considerations for the periodic monitoring/repair maintenance concept are discussed in section 4.3.2.2.

4.3.2 Maintainability Design Considerations for Dormant Systems

The following sections provide maintainability design considerations for the two maintenance concepts previously described for dormant systems. Design considerations for the "wooden round" maintenance concept are discussed in section 4.3.2.1 and design considerations for the periodic monitoring/repair maintenance concept, including guidance in selecting an optimum inspection/test frequency, are discussed in section 4.3.2.2.

4.3.2.1 "Wooden Round" Design Considerations

The objective of the wooden round, maintenance-free storage concept is to design a system and its storage package for the elimination of the need for inspection (except for periodic inspections of the package container to assure its environmental integrity), maintenance, and repair. The design for maintenance-free storage must therefore address the following factors: (Ref. 75)

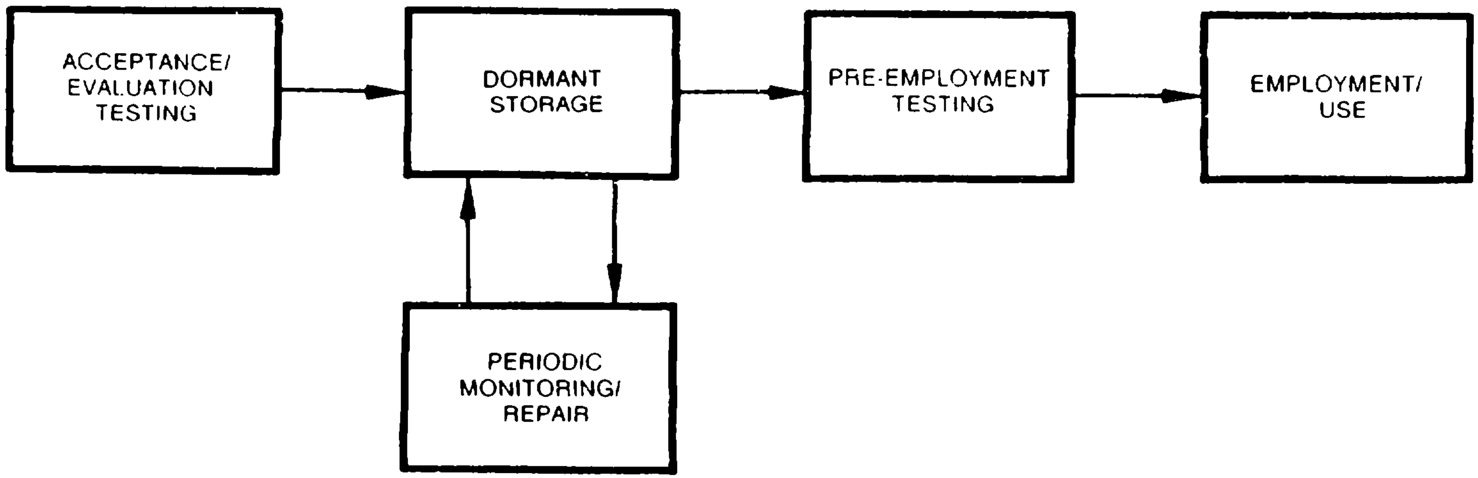

Figure 4.3.1.2-1. Periodic Monitoring/Repair Maintenance Concept

- Use of 100-percent burn-in, screening and preconditioning of parts or subsystems, on both electronic and mechanical items.

- Avoidance of storage-time-critical components and materials (for example, electrolytic capacitors, open contacts, natural rubber, and mineral oils. See section 4.1 for part selection and control guidelines.).

- The system should be designed for simplicity using a minimum of parts. This minimizes the possibility of failures occurring in a numerical sense.

- Use of an inert atmosphere (such as nitrogen).

- Use of transport and storage containers as tactical packaging to mitigate the effects of long-term exposure to life cycle environments (See sections 4.5 and 4.6).

- Interconnection plugs should only be used if no other design is available (cost reduction and increase in reliability).

- Reduction to a minimum of built-in test points for external testing as they are unnecessary and may provide paths for moisture and contamination intrusion.

- Use of a compact structure, combining PC boards and sealing the system.

- Use of digital electronics with no field adjustment.

- Manufacturing and quality assurance methods to increase reliability, through increased usage of automatic test equipment during manufacture.

- Complete documentation of manufacturing parameters and test results.

- Replacement of parts which, due to their present technology, are time change items (lifetime limited, for example, magnetrons). This should be accomplished without any disassembly or test, and the system should remain in its container. Replacement of modules will be limited to the smallest possible individual element.

In order for the wooden round concept to be effectively applied, the reliability of the candidate equipment must exceed the required reliability over the designed storage life of the equipment as shown in figure 4.3.2.1-1. If this is not possible, a cost tradeoff should be made considering the use of redundant equipment to increase the non-operating reliability above the required level vs. a change in the maintenance policy to a periodic monitoring/repair policy (See section 4.3.2.2).

4.3.2.2 Periodic Monitoring/Repair Design Considerations

The objective of the periodic monitoring/repair maintenance concept is to improve the reliability of non-operating equipment by periodically monitoring (testing) the equipment to detect non-operating failures so that they can be repaired before the equipment is called upon to perform a mission. This is illustrated in figure 4.3.2.2-1. As shown in the figure, the wooden round concept reliability does not meet system requirements over the planned non-operating life of the system. However, with the introduction of periodic monitoring and repair, non-operating failures are repaired and the system is able to achieve the desired reliability over the planned non-operating life.

In implementing the periodic monitoring/repair concept, it is very important that the monitoring and repair operations are carefully controlled in order to avoid the introduction of contaminants that will cause long-term non-operating reliability problems, and to avoid failures induced by the monitoring and repair operations, some of which may go undetected. Because of this, it is not recommended that the monitoring and repair operations be performed under field conditions. In order to maintain the highest reliability and availability, the monitoring and repair operations should only be performed be highly trained personnel under environmentally controlled conditions. Handling, teardown exposure times, and test times should be kept to the absolute minimum.

The establishment of the optimum monitoring (test) interval is of primary importance. An interval that is too short will result in needless tests and inspections, lower availability, and an increase in the number of repairs due to maintenance induced errors. An interval that is too long will result in reduced reliability. Two methods for determining the optimum test frequency for periodic testing of dormant systems are presented in the following sections. Section 4.3.2.2.1 provides a method for determining the test frequency which minimizes dormant system unavailability considering the impact of test induced failures. A similar method for determining the optimum test interval for achieving a dormant system end of storage life reliability requirement is presented in section 4.3.2.2.2.

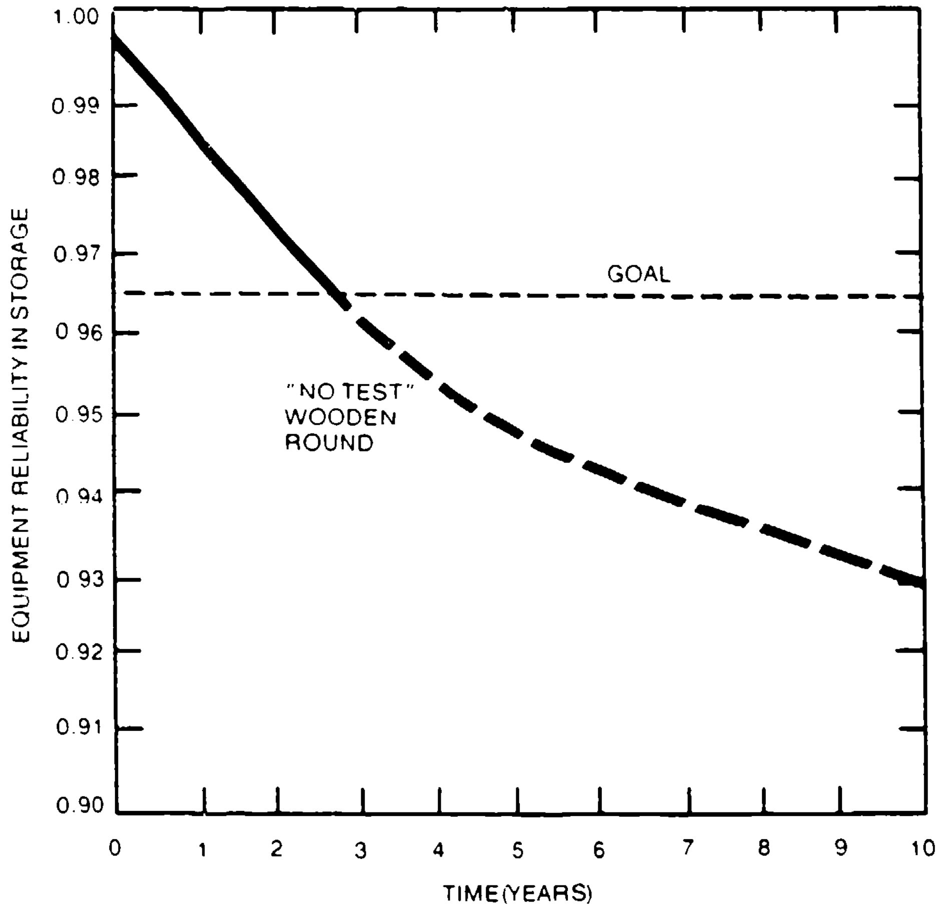

Figure 4.3.2.1-1. "Wooden Round" Reliability Curve

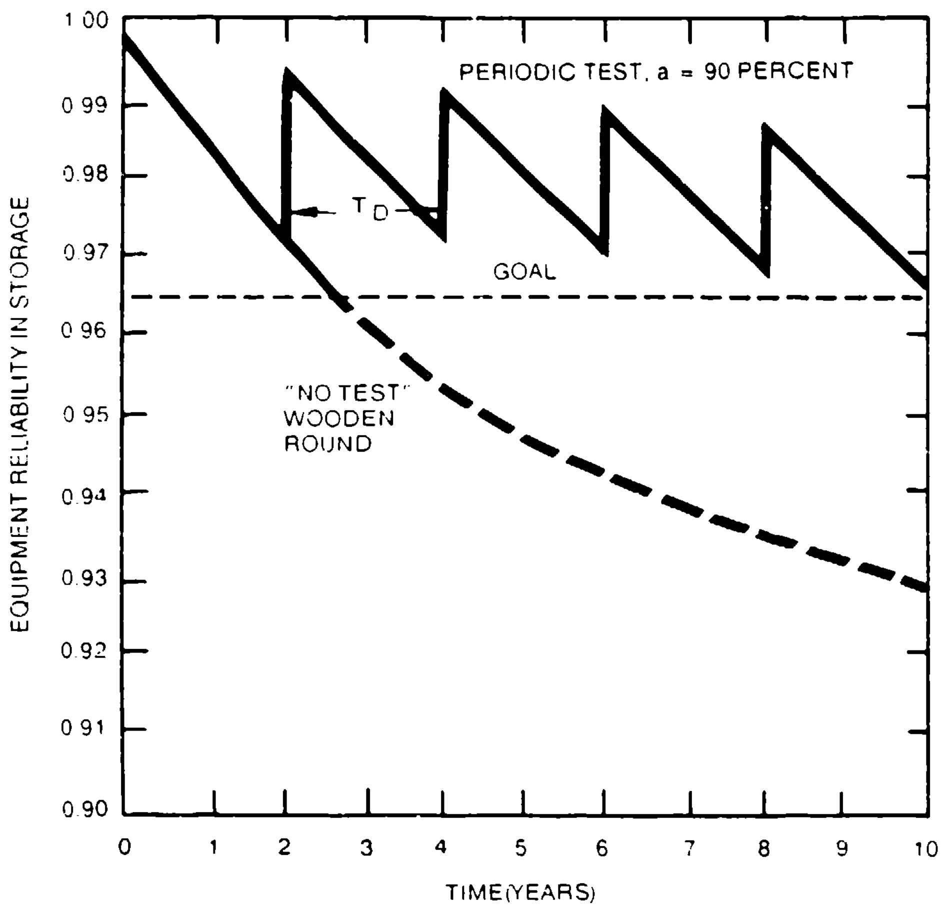

Figure 4.3.2.2-1. Periodic Monitoring/Repair Reliability Curve

4.3.2.2.1 Optimum Test Intervals To Minimize Dormant System Unavailability

S.H. Sim (Ref. 79) has developed a model for determining the optimum test interval to minimize dormant system unavailability under two test policies:

I The system is tested every T hours.

II System tests are conducted W hours after the completion of the last test or after completion of a repair, whichever comes later.

This model is based upon the following assumptions:

- The system is in steady state. Only one system is tested at a given time.
- The system time to failure in the dormant state is exponentially distributed.
- Testing can cause failures in the system that are unrelated to failures in the dormant state.
- All failures are detected during the test.
- The system undergoes repairs immediately on completion of the test after it has failed.

Test Policy I

For Test Policy I, Sim shows that system unavailability U is given by the following:

$$U = \sum_{i=o}^{1} P_i E[D|i]/T$$

where,

P = the probability that the system is in state i just before test.

E[D|i] = the expected downtime between the starts of tests n-1 and n, given that the system is in state i just before test n-1.

T = the fixed test interval.

i = system state, i=0 refers to a good state, and i=1 refers to a failed (bad) state.

Formulae and definitions for the derivation of these parameters are given in Figure 4.3.2.2.1-1.

The optimal test policy is found by minimizing U with respect to T. J.K. Vaurio (Ref. 77) has developed an approximation of this optimum test interval as follows:

$$T_{OPT} \simeq [2(\tau + \alpha/\mu)/\lambda]^{1/2}$$

Examples illustrating the optimum test interval for various conditions are presented in Tables 4.3.2.2.1-1 and 4.3.2.2.1-2.

Test Policy II

For Test Policy II, Sim shows that system unavailability U is given by the following:

$$U = \sum_{i=0}^{1} P_i E[D|i]/E[L|i]$$

where $E[L|i]$ is the expected time interval between the start of tests n-1 and n, given that the system is in state i just before test n-1. Formulae and definitions for the derivation of $E[D|i]$ are given in Figure 4.3.2.2.1-1. All other parameters are as previously defined.

The optimal test policy is found by minimizing U with respect to W. Examples illustrating the optimum test interval for various conditions are presented in Tables 4.3.2.2.1-1 and 4.3.2.2.1-2.

4.3.2.2.2 Optimum Test Interval To Achieve Minimum Dormant Reliability Requirement

As shown in figure 4.3.2.2-1, periodic testing of dormant systems can be employed to achieve a dormant reliability requirement over the planned service life of a system when the "wooden round" maintenance concept fails to do so. The objective in determining the optimum test interval is to make the test interval as large as possible but not allow the reliability to drop below the minimum reliability requirement over the planned service life.

E.C. Martinez (Ref. 78) has shown that the minimum reliability just prior to the N-th periodic test is given by the following:

$$R_{N(MIN)} = e^{-[(N-1)(1-a)\lambda_D T_D]} e^{-\lambda_D T_D}$$

and the reliability after the N-th periodic test is given by:

Figure 4.3.2.2.1-1 Parameters and Definitions for Optimal Test Policies Minimizing Dormant System Unavailability (Ref. 79)

Definitions

i = system state, $i=0$ refers to a good state, and $i=1$ refers to a failed (bad) state.

P_i = probability that the system is in state i just before test.

q_{ij} = probability that the system is in state j just before test n, given that it is in state i just before test $n-1$.

τ = test downtime.

λ = constant failure rate for system.

$\Phi(\lambda)$ = moment generating function of system repair time.

μ = mean repair rate.

α = test-induced failure probability.

U = steady-state system unavailability.

$E[D|i]$ = expected downtime between the starts of tests $n-1$ and n, given that the system is in state i just before test $n-1$.

$E[L|i]$ = expected time interval between the starts of tests $n-1$ and n, given that the system is in state i just before test $n-1$.

Test Policy I (System Tested Every T Hours)

$$q_{00} = (1-\alpha)e^{-\lambda T} + \alpha\,\Phi(\lambda)e^{-\lambda(T-\tau)}$$

$$q_{10} = \Phi(\lambda)e^{-\lambda(T-\tau)}$$

$\Phi(\lambda) = e^{\lambda/\mu}$ for fixed constant repair time.

$\Phi(\lambda) = \mu[1-e^{-(\mu-\lambda)(T-\tau)}]/(\mu-\lambda)[1-e^{-\mu(T-\tau)}]$ for exponential repair times normalized to a specified time interval, $T-\tau$.

Figure 4.3.2.2.1-1 Parameters and Definitions for Optimal Test Policies Minimizing Dormant System Unavailability (Ref. 79)(Continued)

Test Policy I (System Tested Every T Hours) (Continued)

$$P_0 = q_{10}/[1+q_{10}-q_{00}]$$

$$P_1 = [1-q_{00}]/[1+q_{10}-q_{00}]$$

$$E[D|i=0] = T-[1-(1-\alpha + \alpha\,\Phi(\lambda))e^{-\lambda(T-\tau)}]/\lambda$$

$$E[D|i=1] = T-\tau-(1-e^{-\lambda(T-\tau)})\Phi(\lambda)/\lambda$$

$$U = \sum_{i=o}^{1} P_i E[D|i]/T$$

Test Policy II (System Tested W Hours After Last Test/Repair Is Completed)

$$P_0 = e^{-\lambda W}$$

$$P_1 = 1-P_0$$

$$E[D|i=0] = \tau + \alpha\mu^{-1} + W-(1-e^{-\lambda W})/\lambda$$

$$E[D|i=1] = \tau + \mu^{-1} + W-(1-e^{-\lambda W})/\lambda$$

$$E[L|i=0] = \tau + W + \alpha/\mu$$

$$E[L|i=1] = \tau + \mu^{-1} + W$$

$$U = \sum_{i=o}^{1} P_i E[D|i]/E[L|i]$$

Table 4.3.2.2.1-1. Optimal Test Policies for Component in Dormant (Standby) State (Ref. 79)

(No Test-Induced Failure)

τ = 0.5 hour, μ^{-1} = 6.0 hours

Dormant Failure Rate λ (per hour)	Test Policy I			Test Policy II		
	T* (Days)	U* (%)	P_o (%)	W* (Days)	U* (%)	P_o (%)
0.5×10^{-5}	18.6	0.23	99.6	18.6	0.23	99.6
1.0×10^{-5}	13.2	0.32	99.3	13.2	0.32	99.3
0.5×10^{-4}	5.9	0.73	96.5	5.9	0.73	96.5
1.0×10^{-4}	4.2	1.05	93.1	4.1	1.05	93.1
0.5×10^{-3}	1.9	2.47	69.8	1.8	2.46	69.8
1.0×10^{-3}	1.3	3.62	48.8	1.3	3.57	48.7

Table 4.3.2.2.1-2. Optimal Test Policies for Component in Dormant (Standby) State (Ref 79)

(Test-Induced Failure Probability $\alpha = 0.04$)

$\tau = 0.5$ hour, $\mu^{-1} = 6.0$ hours

	Test Policy I			Test Policy II		
Dormant Failure Rate λ (per hour)	T* (Days)	U* (%)	P_o (%)	W* (Days)	U* (%)	P_o (%)
0.5×10^{-5}	22.7	0.27	99.6	22.7	0.27	99.6
1.0×10^{-5}	16.1	0.39	99.3	16.0	0.39	99.3
0.5×10^{-4}	7.2	0.88	96.5	7.2	0.88	96.5
1.0×10^{-4}	5.1	1.26	93.1	5.0	1.26	93.1
0.5×10^{-3}	2.3	2.92	69.8	2.2	2.92	69.8
1.0×10^{-3}	1.6	4.24	48.8	1.6	4.22	48.7

$$R_{N(MAX)} = e^{-[N(1-a)\lambda_D T_D]}$$

where,

N = the number of test periods.
a = the effectiveness of the periodic test in detecting failures.
λ_D = the failure rate for the period between tests.
T_D = the time period between tests (See fig. 4.3.2.2-1)

Based upon these equations, the optimum test interval (T_D) is found by setting the minimum reliability at the last test interval ($R_{N(MIN)}$) to equal the reliability requirement (R_R) of the system:

$$R_R = e^{-[(N-1)(1-a)\lambda_D T_D]} \, e^{-\lambda_D T_D}$$

From this it is seen that:

$$T_D = \ln R_R / [(N(a-1)-a)\lambda_D]$$

where $\ln R_R$ is the natural logarithm of R_R.

The optimum test interval is then found by maximizing T_D such that the following conditions are met:

$$T_D \times N < T_{SL}$$

and,

$$T_D \times (N+1) > T_{SL}$$

where T_{SL} is the planned service life of the system.

As an initial test of whether it is possible to achieve a reliability requirement for a given set of conditions, the limit of $R_{N(MIN)}$ should be calculated as T_D goes to zero. This yields the following:

$$R_{N(MIN)}(T_D=0) = e^{-(1-a)\lambda_D T_{SL}}$$

If $R_{N(MIN)}(T_D=0)$ exceeds the minimum reliability requirement, than an optimum periodic test policy exists. If it is equal to the minimum reliability requirement, then the optimum periodic test policy is to continuously test the system throughout its service life (i.e. $T_D=0$). If it is less than the minimum reliability requirement, then no amount of periodic testing will allow the attainment of the minimum reliability requirement over the planned storage life without an increase in the effectiveness of the periodic test.

The previous discussion does not include the impact of test induced failures. If test induced failures are to be considered, then: (Ref. 78)

$$R_{N(MIN)} = e^{-[(N-1)(1-a)(\lambda_D T_D + F_T)]} e^{-\lambda_D T_D}$$

and,

$$R_{N(MAX)} = e^{-[N(1-a)(\lambda_D T_D + F_T)]}$$

where F_T is the number of test induced failures due to on-off power cycling and powered operation per test period.

The value of T_D that must be maximized to obtain the optimum test interval is then:

$$T_D = \ln R_R/[(N(a-1)-a)\lambda_D] + [(N-1)(1-a)F_T]/[N(a-1)-a)\lambda_D]$$

As before, the optimum test interval is now found by maximizing T_D such that:

$$(T_D+T_T) \times N < T_{SL}$$

and,

$$(T_D+T_T) \times (N+1) > T_{SL}$$

where T_T is the total power-on test time per test period.

4.4 Testability Design

Testability addresses the extent to which a system or unit supports fault detection and fault isolation in a confident, timely, and cost-effective manner.(Ref. 82) Designing a successful testability program involves the accomplishment of the following:

- Preparation of a Testability Program Plan.
- Establishment of sufficient, achievable, and affordable testability, built-in, and off-line test requirements.
- Integration of testability into equipments and systems during the design process in coordination with the maintainability design process.
- Evaluation of the extent to which the design meets testability requirements.
- Inclusion of testability in the program review process.

These tasks are the same regardless of how much time the system will spend in a non-operating state throughout its service life. They are fully described in MIL-STD-2165 (Ref. 82) and will not be repeated here. RADC-TR-82-189 (Ref. 83) is another good testability design reference. Whereas the MIL-STD-2165 treatment of testability pays more attention to the managerial and organizational aspects of the subject, RADC-TR-82-189 is more technically oriented and provides useful guidance for designing testability features into a system. The reader is encouraged to reference both of these documents in establishing a testability program.

Section 4.4.1 discusses testability concepts and section 4.4.2 addresses testability design considerations for dormant systems. This information can then be used in conjunction with the recommended references to develop a successful testability program for these systems.

4.4.1 Testability Concepts

Testability is divided into three concepts: Manual Test, Automatic Test, and Built-In-Test (BIT). Any of these test concepts can be applied at system, subsystem, equipment, card, or component level to aid in fault detection and isolation within that level. All three concepts have been employed in dormant system designs.

In the manual test concept, the test equipment designed during the integration of testability into the design of a system is intended to be manually operated. Manual testing generally relies completely on manual operation, operator decision, and evaluation of results. The manual test equipment may consist of standard "off the shelf" oscilloscopes, voltmeters, signal generators, etc. which are manually attached to specially designated test points external to the system. However, this manual equipment may also be specially designed in itself. The essential characteristics of the manual test concept are that:

a) The test equipment is not an integral part of the system. The test equipment can be removed from the system.

b) Test personnel must manually connect the test equipment to the existing external test points of the system.

c) The operation of the test equipment must be manually initiated by test personnel.

d) Any switchover to redundant equipment in order to maintain system availability must be manually performed.

In the "Automatic Test" concept, the test equipment designed during the integration of testability into the system is designed to be automatically operated. Under this concept, the performance assessment, fault detection, diagnosis, isolation, and prognosis is performed with a minimum of reliance on human intervention. According to MIL-STD-1309 (Ref. 84) definitions, automatic test may include Built-In-Test (BIT), however, throughout the following discussions automatic test equipment is discussed separate from BIT. The automatic test equipment definition in the following refers to a removable stand-alone piece of equipment that is separate from the system. It should also be noted that Automatic Test Equipment (ATE) may sometimes be manually connected to the system and monitored by personnel. However, the definition of such equipment specifies only "minimum reliance on human intervention", not zero reliance on human intervention.

In the "Built-In-Test" (BIT) test concept, the test equipment designed during the integration of testability into a system is designed to be built into the system. BIT refers to an integral capability of the mission equipment which provides an on-board, automated test capability to detect, diagnose, and isolate system failures. The fault detection and isolation capability is used for periodic or continuous monitoring of a system's operational health, and for observation and, possibly, diagnosis as a prelude to maintenance action.

BIT is further subdivided. There is "Initiated BIT" which is a type of BIT which is executed only after the occurrence of an external event such as an action by an operator. There is "Passive BIT" which is non-disruptive and non-interferring to the prime system. There is "Periodic BIT" which is a type of BIT which is initiated at some frequency. An example is BIT software executing during planned processor idle time. There is also "Turn-On" BIT, a specific type of initiated BIT which is exercised each time power is applied to the unit or system.

The essential characteristic of BIT equipment is that it is part of the system itself. Current BIT systems typically use 1% to 10% of the system hardware to test 90% to 100% of the system functions (Ref. 85). For additional information regarding BIT the reader should refer to Reference 85.

The selection of an appropriate testability concept for a system entails cost tradeoffs between the three basic concepts in order to arrive at the most cost effective testability approach that achieves reliability, availability, and supportability requirements at the lowest life cycle cost for the system. The optimum approach may contain a mix of the three basic concepts, or, in the case of some dormant systems, it may contain no testability features. The blind application of an approach such as BIT will not ensure that this objective is met. As previously stated, the steps to be followed in selecting a testability approach for electronic systems and equipments are described in MIL-STD-2165.

4.4.2 Testability Design Considerations for Dormant Systems

The following sections provide testability design considerations for dormant systems. The maintenance concept inpact on the selection of a testability approach is discussed in section 4.4.2.1 and the impact of test effectiveness is discussed in section 4.4.2.2. Section 4.4.2.3 addresses "Go/No-Go" testing versus "Parameter" testing for dormant systems. Finally, testability design guidelines for dormant systems are presented in section 4.4.2.4.

4.4.2.1 Maintenance Concept Impact on Testability

The maintenance concept chosen for a system will have a significant impact on the degree to which testability is designed into a system. In section 4.3, two broad maintenance concepts were identified for dormant systems: "Wooden Round" and Periodic Monitoring/Repair. The "Wooden Round" maintenance concept is essentially maintenance-free storage of equipment through the elimination of organizational level preventive maintenance throughout the storage period. In contrast, the Periodic Monitoring/Repair maintenance concept consists of fixed calendar inspections, operating times, checks, and overhaul of systems throughout the storage period to maintain required reliability and operational readiness states.

The "Wooden Round" maintenance concept objective of maintenance free storage of equipment throughout the storage period implies that system testability is not required. This implication is also reinforced by the common objective that "wooden round" systems require no checkout before use. The attainment of these objectives requires that the system be designed for simplicity using a minimum of parts to minimize the possibility of failures occurring. Since typical BIT systems comprise up to 10% of the system hardware, a significant decrease in the failure rate can be achieved by the elimination of BIT hardware. Built-in test points for automatic or manual external testing may provide paths for moisture and contamination intrusion and they contribute to the overall system failure rate. They are unnecessary and should also be avoided.

The Periodic Monitoring/Repair maintenance concept, on the other hand, implies the incorporation of a high degree of testability in the system. The optimum mix of the three basic concepts of manual, automatic, and built-in-test that should be employed will rely on cost tradeoffs to determine the mix that meets system reliability, availability, and supportability objectives at the lowest life cycle cost.

Regardless of the maintenance concept chosen for a system, the system and its subparts must be designed for testability during fabrication, in-process testing, acceptance testing, and, where appropriate, repair. It is important that this is not forgotten, especially for "wooden round" systems which require no field testability once deployed. The guidelines provided in Reference 83 are applicable to the incorporation of testability at this level of system design.

4.4.2.2 Test Effectiveness Impact on Dormant Systems

Test set fault detection capability has a marked effect upon the feasibility of implementing periodic confidence (go/no-go) testing for dormant systems. When confidence tests are considered, a reduction in fault detecting effectiveness of the test set requires an increase in system production requirements in order to achieve desired mission reliability goals. The level of fault detection that can be achieved is, in turn, dependent upon the configuration of the dormant system and the dormant failure modes.

An analysis of missile system failure rates in a non-operating environment (Ref. 88) suggests that such failure rates are not constant. In fact, the number of missiles failing confidence tests was found to be virtually the same regardless of the dormant storage times. This is attributed to the following: (Ref. 88)

1. Compounding of storage failures with factory recommended stress screen escapes. The number of confidence testing rejects attributed to this item is directly related to the environmental stress screen (ESS) strength and the quality assurance levels applied to vendor piece part screening as well as sub/prime contractors in-house quality control programs.

2. Confidence test set operator errors: technical judgement related to accept/reject criteria and the technical level of the operator.

3. Confidence test set calibration.

4. Confidence test set induced failures and false alarms.

5. Non-operating hours attributed to handling and shipment which are usually equal for dormant storage controlled test.

6. Non-operating hours spent in dormant storage which are directly related to the non-operating environment.

Item (1) is expected to appear as a decreasing hazard rate during dormancy, but at a much slower rate than that observed during operating environments. Items 2-5 are independent of time and should result in a fixed number of failures each time that the confidence test is performed. Failures attributed to items 2-5 can be substantial. According to a Redstone Arsenal study (Ref. 18), as many as 50 percent of confidence test rejected missiles were erroneously faulted or were found to contain test-induced failures. Item (6) is the result of the hazard rate distribution for dormant storage and is assumed to be constant during non-operating periods (i.e. the number of failures will increase as a function of non-operating time.).

It was determined in Reference 88 that regardless of the overall distribution , non-operating failures exert themselves in dormant systems as a direct result of the number of parts used in the system design (i.e. the higher the complexity of the design the higher the fallout during testing). While the level of test rejects related to items 2-5 can be minimized by test set design changes, operator instructions, and BIT enhancement, the factors attributed to items 2-5 will overshadow that expected from item (6) for systems using a small number of parts (e.g. 2000 electrical parts). For such systems, a confidence test would be counter productive. In general, the advantage of implementing confidence testing increases as an inverse function of non-operating reliability.

Mathematical models demonstrating the impact of test effectiveness and test-induced failures on dormant system reliability and availability are presented in section 4.3.2.2.

4.4.2.3 "Go/No-Go" Versus "Parameter" Testing

The time interval between tests for dormant systems is typically quite long, often exceeding 12 months. While the failure mechanisms that occur during non-operating periods are of the same type that occur during operating periods, they occur at much slower rates. Critical to maintaining the reliability and availability of dormant systems is the ability to not only detect failures that have occurred since the last test, but also to determine the likelihood of failures occurring before the next scheduled test or system demand.

Many BIT systems are designed for "go/no-go" testing for the purpose of monitoring the general well-being of the system, informing the operator of any malfunction, and aiding in the location of failed components. Simple "go/no-go" test results, however, are not able to indicate if a system has degraded from the last test but is still operational, or if a failure is imminent. Often an impending failure can be anticipated due to early signs appearing in the main or BIT systems. They can take the form of noise, voltage level changes, excessive current drains, or missing data bits.

Early recognition of these signs can be of great benefit since it could prevent a mission failure. In cases where components are known to degrade over their lifespan and these characteristics can be measured, a test point should be installed. Key parameters should also be monitored and stored for an early failure prognostic by a computer or logic circuit. The removal of a questionable unit and replacement with one that is not suspected of impending breakdown can considerably increase the confidence factor in a mission.

A non-volatile memory such as an EPROM may be used as a maintenance log. It can be incorporated into the BIT test system to store the history of the parameters tested and record component failures. This could then be made available during test periods to determine trends and provide more efficient fault diagnostics. If automatic test equipment is used the equipment can perform this same function. Even if manual testing is employed, the actual parameter values should be recorded and analyzed for trends from test to test rather than just recording whether or not the item passed or failed the test.

4.4.2.4 Testability Design Guidelines for Dormant Systems

As previously stated, the tasks involved in implementing a successful testability program are the same regardless of how much time the system will spend in a non-operating state throughout its service life. Testability program tasks are fully described in MIL-STD-2165 (Ref. 82) and technical design guidance for incorporating testability features are covered in RADC-TR-82-189 (Ref. 83) and the Joint DARCOM/NMC/AFLC/AFSC Built-In-Test Design Guide (Ref. 85). The following guidelines are provided to supplement these sources in designing for dormant system testability:

- The selection of data monitoring points for R & D tests should also be harmonious with those to be required in subsequent stockpile testing. Careful selection should be made to maximize the requirements for the full life cycle of the program while minimizing cost. One way is to design data monitoring points, telemetry counterweights, antenna cutouts, etc., into the final technical data package. In this way, dormant systems randomly selected for testing can easily be modified to accommodate telemetry components, etc. Further, since data monitoring points will be identical to those collected during R & D, results of periodic storage tests can be readily compared to baseline data. (Ref. 89)

- Technical manuals should stress the proper care and procedures to be followed so that unnecessary damage will be avoided. Where extensive handling, mating, and re-assembly of hardware will be required as part of the test, the most used hardware should receive special design attention to make it more rugged and less susceptible to damage.

- Removable hatches (knock-outs) should be incorporated in missile skins to add telemetry antennae for missile flight tests. In addition, standard telemetry connectors should be used. (Ref. 90)

- Components that are designed to respond to environmental stimulae should be designed to be easily disconnected so that they can be connected to simulators for individual testing. (Ref. 90)

- It is erroneous to assume that simply because a mechanical device has been operationally checked that it is as-good-as-new. (Ref. 91)

- Since operating failure rates are higher than non-operating failure rates, equipment "on" time during testing should be minimized to avoid degrading reliability.

- Tests should be carefully analyzed to ensure that they will not induce failures or degrade equipment reliability.

4.5 PACKAGING

The basic purpose of packaging is to ensure that items are fit to perform their intended function when the time comes for them to be used. It must protect an item from the time of production, through transport and storage, to operation and use. The selection of adequate packaging protection must be based on the application of packaging techniques and materials to protect an item against known or anticipated logistics environment conditions. In order to provide this protection, three factors must be known to the designer: (Ref. 46)

(1) The physical and mechanical properties of the item.

(2) The conditions of the environment to protect against.

(3) The technical capabilities of the packaging design to protect the item.

Factors (1) and (2) are covered in Sections 3 and 4.1 of this document. Section 3 discusses dormancy environments and provides general guidelines for protecting equipment from the effects of the natural and induced environmental factors experienced in these environments. Section 4.1 presents part selection and control information and provides specific information concerning the impact of these environmental factors on the various piece parts that make up electronic equipment designs. The third factor is the subject of this section.

Proper protection against damage and deterioration of components and equipment during shipment and storage involves the evaluation of a large number of interactive factors and the use of tradeoff analysis to arrive at a cost-effective combination of protective controls. MIL-P-116 (Ref. 47) describes six basic methods of preservation to protect equipment against corrosion, physical and mechanical damage, and other forms of deterioration. These methods differ in the amount of protection afforded against environmental factors. The six methods are:

I Preservative coating applied, wrapper not sealed. Water as liquid or vapor and corrosive atmosphere has relatively free contact with the equipment.

IA Preservative coating applied as required, water- vaporproof barrier sealed. Only traces of water-vapor penetration to equipment is possible.

IB Equipment, wrapped or unwrapped, is enclosed within a coating of strippable compound. No penetration of liquid and only traces of water-vapor can penetrate to the equipment.

IC Preservative coating is applied as required, waterproof or water-resistant barrier is sealed. Only water-vapor can penetrate to the equipment.

II Preservative coating is applied as required; waterproof, water-vaporproof barrier is sealed with dessicant inside. Only traces of water-vapor can penetrate to the equipment and this is absorbed by dessicant.

III No preservative is applied to the equipment. The equipment is packaged for physical and mechanical protection only. Liquid and water-vapor has relatively free access to the equipment.

The amount of protection required is dependent upon the environment to which the equipment will be subjected and the susceptibility of the equipment to damage by this environment. If electronic equipment is to be stored in a dry, well-ventilated warehouse, where the temperature of the air surrounding the equipment can be regulated so that it does not fall to dewpoint values, then relatively little protection is required such as afforded by Methods I and III. Generally, however, this is not the case for most military equipment and more protection will be required such as afforded by Methods IA, IB, IC, and II.

The amount of protection to apply should be based upon the worse case conditions to which the equipment is likely to be exposed. This is especially true for dormant equipment designs since any degradation that does occur during non-operating periods may go unnoticed for long periods of time, possibly resulting in equipment failure and loss of mission. As stated in Section 4.1, the most important environmental stresses during non-operating periods are mechanical, chemical and low thermal. The minimal packaging for dormant equipment designs should provide protection from these stresses.

A detailed discussion of packaging designs is beyond the scope of this document. Detailed guidelines for packaging and protecting equipment are presented in references 48 and 49. Reference 48 is a design handbook for packaging and pack engineering and reference 49 presents design guidelines for the prevention and control of corrosion. The following sections provide additional information applicable to the packaging and protection of dormant electronic equipment. Section 4.5.1 presents a discussion of material degradation. Section 4.5.2 discusses cleaning methods and 4.5.3 discusses the dielectric embedding of electrical and electronic assemblies. Assembly packaging issues are discussed in section 4.5.4 and shipping and storage container design is covered in section 4.5.5. Finally, section 4.5.6 presents guidelines for the development of in-storage cyclic inspections.

4.5.1 Material Deterioration

This section describes the fundamental factors causing deterioration of materials, the effect of climatic conditions on materials, and the recommended storage conditions for different types of materials. Materials are classified into two basic groups: metal and organic materials. It can generally be stated that metals deteriorate primarily by electrochemical processes while organic materials generally undergo deterioration due to chemical reactions. Many of the factors which are influential in the process of deterioration are present everywhere in the atmosphere. With an understanding of the deterioration of these fundamental material types the design engineer will be more effectively prepared to design proper preservation and packaging for the dormant environment.

4.5.1.1 Metal Deterioration

The principle deterioration mechanism for metals is corrosion. Corrosion is a process that occurs when metals are placed in contact with water or a chemical solution. There is a tendency for electrically charged metal particles (ions) to go into solution. Because the solution must remain electrically neutral an equivalent number of positive ions of another element must be displaced. In the case of a metal such as iron in water, hydrogen is plated out on the surface of the metal as a thin film, known as corrosion (or rust).

The most important effects of temperature on the corrosion of metals are its relation to solubility and chemical reactions. An increase in temperature generally increases the rate of chemical reactions and reduces the solubility of gases in solution. Changes in temperature may also affect the solubility of reaction products in such a manner as to change the nature of the corrosion products. (Ref. 50)

In order to prevent corrosion of metals, control must be extended over the influencing factors. The prevention of metal corrosion during storage relies on the use of various coatings, inhibitors and passivators, and dehumidification.

There are two types of protective metallic coatings that can be used to inhibit corrosion. Cathodic coatings coat the metal surface with a more noble metal resulting in reduced corrosion. Pinholes and discontinuities in the coating accelerate localized corrosion where the base metal is exposed. Care must therefore be used in the application of cathodic coatings and in some cases it may be advisable to apply an outer insulating coating. Anodic coatings, being more anodic than the base metal are preferentially attached in the electrolytic process. The anodic protective properties will however, eventually degrade. The anodic coating will still provide a protective coating even if the coating is likely to be broken or contain pinholes. (Ref. 50)

Organic coatings are widely used in the protection of metal surfaces from atmospheric corrosion. They act as mechanical barriers preventing corrosive mediums from reaching the metal surface. The performance of an organic compound is therefore largely dependent on its permeability and its ability to adhere to the metallic surface and in many cases it is necessary to apply more than one coat to obtain satisfactory results.

An inhibitor may be defined as any chemical substance or mixture that effectively decreases the corrosion rate when added in small amounts to a corrosive environment. The type of material to be protected and the environment to which it is subjected must be thoroughly understood before the selection of the inhibitor can be made. An inhibitor may effectively decrease the corrosion of a metal in one environment and actually promote corrosion of the same metal in a different environment. In some cases, an inhibitor may decrease and at the same time promote localized pitting. (Ref. 50)

Passivators are inhibitors which change the electrode potential to a more noble value. The tendency of an anodic inhibitor to act as a passivator is greater than that of a cathodic inhibitor. The ability of an inhibitor to act as a passivator as well as the amount of inhibitor required are dependent upon the type of metal, the environment, and the temperature. (Ref. 50)

Dehumidification is a method of preventing metal corrosion by reducing the amount of water vapor which is in the air. By proper humidity control it is possible to keep the moisture content of air at a level low enough so that corrosion is not promoted. The term humidity control applies equally to both air conditioning processes of humidification and dehumidification. These two processes are differentiated by the fact that one adds moisture and one removes moisture from the air.

For a detailed discussion of the factors influencing corrosion, forms of corrosive attack including stress-corrosion cracking and hydrogen-stress cracking (hydrogen embrittlement), corrosion characteristics of metals, general methods of protecting metals and alloys from corrosion, and information on corrosion testing, the reader should refer to MIL-HDBK-729.

4.5.1.2 Organic Deterioration

The basic unit of composition of many organic materials is either cellulose or hydrocarbon derivatives and they can be affected by numerous chemical factors. Upon exposure to undesirable conditions, a chemical change takes place which results in changes in the physical properties of the materials. The changes brought about by the factors are not common to all materials and likewise the degree of exposure to such factors produces varied results. The chemistry involved in the chemical changes taking place in the deterioration of organic materials is extremely complicated and cannot be discussed within the scope of this text. However, it is intended that this discussion will cover the highlights of most organic materials and the factors which are primary in causing deterioration. This section gives a brief overview of the material found in Reference 51.

The deterioration of plastic and rubber materials is difficult to describe without becoming involved in lengthy discussions of each individual compound. Plastics and rubber are usually considered in the same light because they basically have the same molecular structure. They are referred to as polymers of high molecular weight. Chemical deterioration of plastics results in cracking, reduced strength, warping, and loss of transparency. Chemical changes in polymers depend to a large extent upon the basic design of the polymer. Polymers are classified in two main groups according to the molecular structure - (1) linear or chain polymers and, (2) branched network polymers. The linear polymers are often referred to as thermoplastics and the branched polymers as thermosetting polymers.

Electrical equipment in general consists of a combination of organic materials and metals assembled together. It follows that the basic materials of construction are affected by the same physical and chemical agents. This type of equipment when exposed to moisture not only undergoes metal corrosion and insulation deterioration, but electrical properties and performance are also affected.

The deterioration of materials of organic origin is to a large extent dictated by the end use of the material and the degree of exposure to which the material is subjected. By anticipation of the end use of the material it is possible to add or provide resistance to exposure and thereby increase the shelf life of the material. Many organic materials cannot be treated in a manner similarly used for metals by protective coatings and surface treatments to improve resistance to various undesirable elements of exposure. The general procedure in this case is to either condition the environment to remove the environmental factor causing the deterioration or select a material that will not be adversely affected by the environment. For example, to give added resistance to materials which are affected by exposure to the physical elements such as heat, sunlight and moisture, additives are added which tend to retard the chemical reactions which take place when these materials are exposed.

Great care must be exercised in using organic materials in dormant designs, especially in low pressure environments and in sealed assemblies, because they may outgas harmful contaminants. Reference 11 should be consulted for outgassing data on organic materials.

4.5.2 Cleaning

The overwhelming area of concern for long-term non-operating reliability is the influence of chemical contaminants. They can be introduced at any point in the fabrication process and include fingerprints, perspiration, inorganic residues, organic residues, water, and other liquids. To obtain the maximum benefits from the various preservation and packaging methods, items must be perfectly clean prior to preservation and packaging in order to prevent any chemical action that might result in corrosion or other forms of deterioration resulting from these contaminants. Basic cleaning requirements are established in MIL-P-116. To maximize the reliability of long-term non-operating equipment, the methods and procedures for precision cleaning described in MIL-HDBK-407 should be followed.

4.5.3 Dielectric Embedding

To isolate circuit components from the degrading effects of environmental factors such as oxygen, moisture, heat and cold, and mechanical shock and vibration, components and assemblies can be coated, buried, or encased in dielectric materials. The earliest substances used for such purpose were materials such as waxes and asphaltic materials. These are now used to a limited extent. Synthetic polymers are currently most widely used for embedding. (Ref. 52)

The materials most employed are epoxy resins. Other materials commonly used are the polyurethanes and the silicones. Additional types finding special uses are vapor-deposited polyxylylenes. Thermosetting hydrocarbons, thermosetting acrylics, polyesters, and polysulfide resins are used less often. (Ref. 52)

Embedding does not provide hermetic sealing, however, it increases the reliability of any given assembly by sealing it against moisture, dirt, fungi, and other contaminants. Also, components are fixed in position resulting in the mechanical strength of the embedded assembly being greatly enhanced against vibration and shock.

There are some limitations in the use of embedded electrical and electronic assemblies. Many are hard to repair. Although flexible and rubberlike polymers can be repaired, any repair can present difficulties. Additionally, the weight of an assembly is increased by embedding since in most cases the amount of additional mechanical structure for protection without embedding can be designed to be relatively light. Embedding resins have higher dielectric constants and loss tangents than air which limits their use in applications where very low electrical loss is a desirable factor. Offsetting this is the fact that voltage breakdown between two potential points is improved. The advantages and disadvantages of embedding electronic/electrical components are summarized in Table 4.5.3-1. For further details concerning the embedding of electronic/electrical assemblies including the selection and application of coatings and embedments which will minimize failures due to moisture, corrosion, and biological degredation during dormant periods the reader should refer to reference 52.

4.5.4 Assembly Packaging

This section provides guidelines for assembly level packaging of equipment to mitigate the effects of environmental factors relevant to dormant periods. Section 4.5.4.1 covers moisture protection measures and section 4.5.4.2 covers sand and dust protection measures. Mechanical shock and atmospheric pressure protection measures are covered in sections 4.5.4.3 and 4.5.4.4 respectively. Solar radiation is addressed in section 4.5.4.5 and electromagnetic radiation is addressed in section 4.5.4.6. Finally, section 4.5.4.7 addresses nuclear radiation.

4.5.4.1 Moisture Protection

Moisture is present in various environments, such as: humidity, rain, snow, and fog. Humidity closely follows temperature in importance as an environmental factor. (Ref 7) Moisture is a chemical and is probably the most important chemical deteriorative factor of all. Moisture is not simply H2O, but usually is a solution of many impurities. In addition to its chemical effects, such as the corrosion of many metals, condensed moisture also acts as a physical agent. An example of the physical effects of moisture is the damage done in the locking together of mating parts when moisture condenses

Table 4.5.3-1. Advantages and Disadvantages of Embedding Electronic/Electrical Components (Ref. 52)

1 Advantages.

a. Use Reliability:

(1) Sealing (not fully hermetic) against fungi, water vapor, and gross moisture, dirt, gases; assemblies are fixed in resin of known mechanical and dielectric characteristics.
(2) Packaging strength (shockproofing, antivibration response) increased.

b. Improved Design:

(1) Air spaces are eliminated.
(2) Components are held in compact three-dimensional form.
(3) Wider application of module construction, miniaturization, and plug-in units is permitted.
(4) Selection of resins allows upgrading of electrical performance (e.g., low-loss response of high frequencies, increased thermal resistance, and/or heat dissipation).
(5) Colored resins may be used for identification of circuit components.
(6) Electrical noise in high-gain amplifier devices is reduced.

c. Economy:

(1) Most or all mounting hardware which may add up to 25-30% weight to an assembly is eliminated.
(2) Need for auxiliary protection for the components is reduced or removed since the resin matrix now serves this purpose.
(3) Less skilled personnel can remove and replace embedded units.
(4) Circuit assembly is more rapid since use of point-to-point wiring can be made (e.g., in place of circuit boards).

2 Disadvantages:

a. Difficult Repairs:

(1) Embedded assemblies are not easily accessible for making minor repairs.
(2) Solvent soaking procedures are difficult.
(3) Hole-drilling (with transparent matrices) is expensive and time-consuming.
(4) Embedded circuit must be treated as an expendable unit (though costly, embedding can be shown to increase reliability and prevent tampering).

b. Lowered Heat Dissipation:

(1) Thermal dissipation in resins is lower than in air -- temperature derating may be required.
(2) Heat-sink and other sophisticated design variants may be required to control heat buildup.

c. Thermal Limits.

(1) Most resin stability is limited above 200°C (certain silicones can surpass this temperature).
(2) Certain high-temperature rated components are required in various systems and require special packaging (but in many uses moderate temperature limits are satisfactory).
(3) With low temperatures, sharp and irregular parts of components can possibly cause resin cracking. Filled or flexible resins improve low temperature performance but at the general sacrifice of electrical properties (however, silicone elastomeric resins can be used with sharp-edge assemblies).

d. Weight Increase

(1) Certain applications can add excess weight to an assembly.
(2) Design techniques may be required in certain instances (e.g., air-borne or space components) to reduce weight; (e.g., use of conformal coating rather than potting or casting).
(3) Certain foamed resins and low density (hollow bead) compounds can be used to reduce weight.

e. Adverse Dielectric Properties

(1) Components can increase circuit capacitance by having dielectric constants close to that of the embedding resin.
(2) With high frequency output, electrical losses can be increased, however, design methods can be used to compensate for known dielectric properties, uniform for given conditions, in the circuit.

f. Variable Stresses in Cured Matrix

(1) Shrinkage occurs during resin curing.
(2) Difference in coefficients of thermal expansion (resin/metal/glasses/other materials) is a source of problems — i.e., breakage, crushing, other component damage but effects are lessened with use of flexibilized resin, or elastomer coatings, e.g., silicones.

on them and then freezes. Similarly many materials that are normally pliable at low temperatures will become hard and perhaps brittle if moisture has been absorbed and subsequently freezes.

Moisture in conjunction with other environmental factors, creates difficulties that may not be characteristic of the factors acting alone. For example, abrasive dust and grit, which would otherwise escape, are trapped by moisture. The permeability (to water vapor) of some plastics is related directly to their temperature. The growth of fungus is enhanced by moisture, as is the galvanic corrosion between dissimilar metals. (Ref 1)

Salt fog environments can be a particularly severe source of moisture degradation. It severely promotes corrosion effects in metallic components and can foster the creation of galvanic cells, particularly when dissimilar metals are in contact. Another deleterious effect of salt fog is the formation of surface films on nonmetallic parts which cause leakage paths and degrade the insulation and dielectric properties of these materials. Absorption of the salt solution by insulating materials can cause a significant increase in volume conductivity, and dissipation factor of materials so affected.

Some design techniques that can be used singly or combined to counteract the effects of moisture and to minimize moisture intrusion are: (Refs. 1, 49)

(1) eliminate moisture traps by providing drainage or air circulation,
(2) use dessicant devices with humidity indicators visible from outside the equipment to remove moisture when air circulation or drainage is not possible, and change the dessicant when the indicator registers greater than 20% relative humidity,
(3) use parazylylene or other conformal coating on printed wiring boards (see section 4.5.3),
(4) use clear conformal coatings to coat exposed surfaces,
(5) provide rounded edges to allow uniform coating of protective material,
(6) use materials resistant to moisture effects, fungus, corrosion, etc.,
(7) use hermetically sealing components, gaskets and other sealing devices,
(8) use impregnating or encapsulating materials with moisture resistant waxes, plastics, or varnishes,
(9) separate dissimilar metals, or materials that might combine or react in the presence of moisture, or of components that might damage protective coatings,

(10) use "O" rings for sealing around all control shafts that must penetrate into the enclosure,
(11) avoid the use of knurled wheels that intrude into the enclosure. Effective sealing around such wheels is extremely difficult,
(12) access plates utilizing a gasket for sealing are less subject to leakage when mounted on a vertical surface,
(13) mount electrical connectors horizontally (through vertical sides). If it is essential to mount a connector vertically on the top of a housing, provide a slightly (at least 3/16 of an inch) raised base for the connector mounting relative to the surrounding horizontal area,
(14) use an "L" type connector so the wiring enters horizontally into the upper portion of a vertically mounted connector,
(15) for all multicontact connectors, wiring should lead upward toward the connector to prevent water from running along wire into the connector. Strain relief is essential to ensure no side loads exist on wires entering backshell grommets or potting.
(16) use solder flux with the lowest possible acid content to minimize acid induced corrosions,
(17) mount printed wiring boards vertically with the edge connectors on vertical edge or back of board
(18) mount equipment and components at least 1/2 inch above potential standing water level.
(19) thoroughly clean all items to remove contaminants such as residual process chemicals, etc.

The design engineer should design on the assumption that moisture will eventually get into the equipment. Except for hermetically sealed or pressurized equipment, this means protection from moisture effects must be provided inside of the equipment, and provisions must be made to let the water drain out of the equipment. (Ref. 49)

Ideally, the maximum resistance to moisture is achieved by the hermetic sealing (solder or glass fusion) of an equipment or component. The hermetic sealing must include a dry, inert gas atmosphere within the sealed box.

There remains much controversy over what is an acceptable level of water vapor within a hermetically sealed package. Livesay (Ref. 3) suggests that 200 ppm of water vapor is the maximum allowable for high reliability. For a package with an internal volume of 2200 cm^3, a leak rate of 2×10^{-12} atm cm^3 sec^{-1} would be required to maintain the moisture content below the 200 ppm level for 10 years. Such a seal is very difficult to attain. In addition, cooling requirements, size (rigidity), container penetrations for wiring and similar considerations also generally preclude hermetic sealing. (Ref. 49)

The next greatest resistance to moisture is obtained through the use of a pressurized equipment housing or compartment. The introduction of pressurized dry air into a semi-sealed (organic seals vice solder or glass fusion) area greatly minimizes moisture intrusion while there is a positive pressure differential over ambient. During periods when positive pressurization is not available, however, there will be increased diffusion of ambient air into the housing or compartment. While this is a very effective means to minimize moisture intrusion, the additional weight required to achieve the necessary housing rigidity and pressure tight sealing has largely precluded the use of this configuration.

For equipment with neither hermetic sealing nor pressurization, protection is best achieved by applying a sealant to prevent all fluid intrusion. Two types of sealants that are often used for this type of application are polysulfide sealants and RTV (silicone) sealants. Non-acetic acid cure RTV is useful for sealing small areas. Clear types of RTV allow visual inspection of the sealed surface, however, these clear RTV may be susceptible to damage by operational fluids. Acetic acid cure RTV should not be used to seal equipment, because acetic acid will cause corrosion. Table 4.5.4.1-1 lists those RTVs (silicone sealants), adhesives, and coatings considered corrosive. For further information concerning non-hermetically sealed assemblies and the use of dielectric embedding as a means of protecting against moisture, dirt, fungi, and other contaminants, the reader should refer to section 4.5.3 and references 49 and 52.

The designer must also consider possible adverse effects caused by specific methods of protection. Hermetic sealing, gaskets, protective coatings, etc., may for example, aggravate moisture difficulties by sealing moisture inside or contributing to condensation. The gasket materials must be evaluated carefully for outgassing of corrosive volatiles or for incompatibility with adjoining surfaces or protective coatings. Other materials sealed within the assembly or container should also be evaluated for outgassing of corrosive volatiles. Solid and liquid propellents in all-up-round (AUR) configurations are of particular concern to the long-term non-operating reliability of dormant systems.

4.5.4.2 Sand and Dust Protection

Sand and dust primarily degrade equipment by: (Ref 1)

(1) Abrasion leading to increased wear,

Table 4.5.4.1-1. Corrosive Silicone Sealants, Adhesives, and Coatings (Ref. 69)

RTV Q3-6090	RTV 785	RTV 92-018	RTV 103
RTV 140	RTV 891	RTV 92-024	RTV 106
RTV 142	RTV 1890	RTV 92-048	RTV 108
RTV 236	RTV 3144	RTV 92-055	RTV 109
RTV 730	RTV 20-046	RTV 94-002	RTV 112
RTV 731	RTV 20-078	RTV 94-003	RTV 116
RTV 732	RTV 30-079	RTV 94-009	RTV 118
RTV 733	RTV 30-121	RTV 94-034	RTV 154
RTV 734	RTV 90-092	RTV 96-005	RTV 156
RTV 780	RTV 92-005	RTV 96-080	RTV 192
RTV 781	RTV 92-007	RTV 96-081	RTV 198
RTV 784	RTV 92-009	RTV 102	

(2) Friction causing both increased wear and heat, and
(3) Clogging of filters, small apertures, and delicate equipment.

Equipment having moving parts require special care when designing for sand and dust protection. Sand and dust will abrade optical surfaces, either by impact when carried by air, or by physical abrasion when the surfaces are improperly wiped during cleaning. Dust accumulations have an affinity for moisture and, when combined, may lead to corrosion or the growth of fungus.

In the relatively dry regions, such as deserts, fine particles of dust and sand readily are agitated into suspension in the air where they may persist for many hours, sometimes reaching heights of several thousand feet. Thus, even though there is virtually no wind present, the speeds of vehicles or vehicle-transported equipment through these dust clouds can cause surface abrasion by impact, in addition to the other adverse effects of the sand or dust. Although dust commonly is considered to be fine, dry particles of earth, it also may include minute particles of metals, combustion products, solid chemical contaminants, etc. These other forms may provide direct corrosion or fungicidal effects on equipment, since this dust may be alkaline, acidic, or microbiological.

Since dust is present in almost any environment, the question is not whether to allow dust to enter, but, rather, how much or what size dust could be tolerated. The problem becomes one of filtering any circulating air to remove dust particles above a nominal size. The nature of filters, however, is such that for a given working filter area, as the ability of the filter to stop increasingly smaller dust particles is increased, the flow of air or other fluid through the filter is decreased. Therefore, the filter surface area either must be increased, the flow of fluid through the filter decreased, or the allowable particle size increased, i.e., invariably there must be a compromise. Sand and dust protection, therefore, must be planned in conjunction with protective measures against other environmental factors. It is not practical, for example, to specify a protective coating against moisture if sand and dust will be present, unless the coating is carefully chosen to resist abrasion and erosion, or is self-healing.

4.5.4.3 Vibration and Shock Protection

Electronic equipment is often subjected to environmental shock and vibration during normal use and testing. Such environments can cause physical damage to components and structural members when deflections produced cause mechanical stresses which exceed the allowable working stress of the constituent parts.

The natural frequencies of subsystems comprising the equipment are important parameters which must be considered in the design process since a resonant condition can be produced if a natural frequencies within the vibration frequency range. The resonant condition will greatly amplify the deflection of the subsystem and may increase stresses beyond the safe limit. The vibration environment can be particularly severe for electrical connectors since it may cause relative motion between members of the connector. This motion can produce fret corrosion which generates wear debris and causes large variations in contact resistance.

The most critical mechanical stress applied to a system is that of shock. Shock occurs when the equipment is subjected to a suddenly applied force, for example acceleration, gunfire, or when a system falls freely. Shock damage is caused by acceleration forces developed during impact. A methodology for calculating the impact force experience by a system is presented in Reference 46. The underlying principle behind all mechanical stress protection packaging is that every accelerating object possesses kinetic energy which it must dissipate by decelerating through a given distance and time interval. More comprehensive guidelines for designing systems to withstand mechanical stresses are presented in section 4.5.5 (Container Design).

4.5.4.4 Pressure Protection

The effects of pressure are not sufficiently common to make it one of the more important environmental factors. Pressure variations due to meteorological processes range from lows of about 880 mb to an upper extreme of 1,083 mb. The low pressures are associated with the eyes of tropical storms while the high pressures are associated with winter time continental high pressure systems.

Pressure variations also are associated with changes in altitude. As altitude increases, the mass of the air above a given point decreases and, consequently, the pressure decreases.

Variations in pressure can cause the rupture of seals, distort containers, or move objects. Pressure changes cause leakage of fluids from containers and control systems, the condensation of trapped water vapor, and equivalent effects. Other effects of pressure include those phenomenon associated with the availability of a certain amount of air. Combustion processes are less efficient at lower pressures, the lubrication capability of oils and greases decreases, electrical breakdown occurs more frequently, heat transfer is less efficient, and liquids vaporize more readily. Design engineers should be alert to these effects of pressure on materials chosen for application in pressure changing environments.

4.5.4.5 Solar Radiation

The effects of solar radiation on material are often similar to those of high temperature since solar radiation elevates the temperature of many materials quite rapidly. Nonthermal effects, however, are important. The high energy short wavelength components of solar radiation induce reactions in materials that often deteriorate their functional properties. Textiles, paper, plastics, rubber, and various surface coatings are susceptible to solar radiation induced changes. A commonly observed effect is that of bleaching of colors from textiles through the action of sunlight. This is brought about through chemical changes in the dyes induced by the ultraviolet portion of the solar radiation. Solar radiation is an environmental factor for which special material requirements are established that may be as costly as the deteriorating effects that solar radiation has on materials.

4.5.4.6 Electromagnetic Radiation

Electromagnetic radiation can cause disruption of performance levels and, in some cases, permanent damage to exposed equipment. Electromagnetic radiation often produces interference and noise effects within electronic circuitry which can impair the functional performance of the system. Sources of these effects include corona discharges, lightning discharges, sparking and arcing phenomena. These may be associated with high voltage transmission lines, ignition system, brush-type motors, and even the equipment itself. (Ref 1)

Protection against the effects of electromagnetic radiation has become a sophisticated engineering field of electromagnetic compatibility design. The most direct approach to protection is, in most cases, to avoid the region in which high levels of radiation levels are found. When exposure cannot be avoided, shielding and filtering are important protective measures. In other cases material design changes or operating procedural changes must be instituted in order to provide protection. (Ref 1)

4.5.4.7 Nuclear Radiation

Although a natural background level of nuclear radiation exists, the only nuclear radiation that is of interest is that associated with man made sources such as reactors, isotope power sources, and nuclear weapons. The most important of these sources is nuclear weapons, the effects of which can produce both transient and permanent damaging effects in a variety of materials.

X rays, gamma rays, and neutrons are the types of nuclear radiation of most concern. As opposed to charged nuclear particle, which also emanate from nuclear reactions, those forms of radiation listed have long ranges in the atmosphere; thus, they can irradiate and damage a variety of materials.

Among the nuclear effects that have been of most concern to operating equipment are those called "Transient Radiation Effects on Electronics". They are due to the transient radiation pulse from a tactical nuclear burst and are often referred to as TREE. These transient effects are due primarily to the ioni ation and total dose effects of gamma rays and X rays, as well as induced permanent lattice defects due to neutron fluence.

The effects of gamma and X rays on unpowered devices is negligible. Neutrons, however, damage the lattice structure of active devices under any bias condition and will result in degraded performance or failure of the equipment. In addition to these effects, the physical properties of polymers will be affected by ionizing radiation such as gamma rays, X rays, and neutrons. This may lead to a loss of structural integrity and electrical properties. For a more detailed discussion of the effects of nuclear radiation on equipment, the reader should refer to references 16, 43, 44, and 45.

It is impossible to completely protect materials items from nuclear radiation as can be accomplished for some other environmental factors. The variety of effects produced by nuclear radiation for different materials and components makes protective design difficult. The procedure employed is to define a radiation hardness level in a given material item and to design and test the item to that level. (Ref. 1)

4.5.5 Container Design

The level of mechanical protection required of a container is dictated by the characteristics of the object to be protected and the environment in which the container must operate. The previous sections have described the need for protection of various materials in various environments. This section will describe container design guidelines.

Of prime importance to container design is the characteristic of fragility. This relates to the ability of an object to withstand the effects of externally applied mechanical forces. The term fragility pertains to the sensitivity of the object to damage and alludes to its degree of inherent elasticity. The basis for the measurement of fragility is the G_m; a dimensionless ratio of the maximum acceleration that an object can safely withstand to the acceleration due to gravity: (Ref. 46)

$$G_m = a/g, \text{ g-units}$$

where a = maximum allowable acceleration an object can safely withstand, ft/s^2
g = acceleration due to gravity, 32 ft/s^2

Essentially, G_m is a measure of the items elasticity, i.e., its inherent capacity to retain or recover its shape upon or after the application of a distorting force. If the force is in excess of the Gm of the item, the elastic limit of the item may be exceeded and result in permanent distortion. An item with a low Gm is considered fragile; one with a high G_m is considered rugged. The purpose of the container is to attenuate--to a level equal to or less than the critical G_m factor of the item to be protected--the forces transmitted to its contents. The magnitude of these forces and their duration constitute the hazard, and it is these forces with which the designer is most concerned.

The most critical of externally applied forces imposed upon the container is that of shock. Shock occurs when the container is subjected to a suddenly applied force, such as when the container is dropped upon a rigid surface. Shock damage is caused by acceleration forces developed during impact.

The underlying principle is that every object in a free-fall possesses kinetic energy which it must dissipate by decelerating through a given distance and time interval. The rate of decceleration is determined by the maximum number of g's G_m that the item can withstand. The rate of deceleration of the impacting object becomes a function of the resistance of the object to crushing or the density of the protective cushion or elasticity of the suspension system. The density or elasticity of the suspension material and ability to preclude the deflection required, determine the amount of shock experienced by the object subjected to impact. If the suspension does not provide for sufficient deflection and gradual increase in stiffness, bottoming may occur with consequent transmission of excessive forces. Reference 25 demonstrates in detail the methods for calculating G_m, and the identified shock parameters.

A condition peculiar to material in transit is that of vibration generated by the carrier vehicle. The carrier, functioning as a fluctuating force, imparts to the container a forced vibration; the container (assumed to be restrained) is forced to vibrate at the same frequency as the carrier. Should these vibrations coincide with the natural frequency of the suspended contents, the associated forces may become great enough to cause fracture or damage to the contained item. The following is a general summary of the most common forcing frequencies that will be encountered by different carriers: (Ref. 46)

(a) Railroad : 2 to 7 Hz
(b) Truck: 5 to 500 Hz
(c) Aircraft: 20 to 60 Hz
(d) Ships: 11 to 100 Hz

The mode of transportation and the applicable frequencies tabulated provide the required data relating to imposed vibrations.

The natural frequency of a container system is that frequency at which the system will vibrate if displaced and allowed to vibrate freely. Any system comprised of a body suspended on cushioning has a natural frequency at which it will vibrate with greater amplitude than at a frequency just above or below it. To determine a rough approximation of the natural frequency of a container system apply the following formula: (Ref. 46)

$$f_n = 2Gm/(h)^{1/2}, \text{ Hz}$$

where G_m = G-factor of the container as designed, g-units
h = drop height, inches
f_n = approximate natural frequency, Hz.

The amplitude of vibration depends upon the magnitude of the forced vibration and the ratio of its frequency to the natural frequency of the object or system being vibrated. When this frequency ratio becomes equal to unity, the amplitude of vibration may build up to a dangerous value. Theoretically, for the effective isolation of vibratory forces, the ratio between the disturbing frequency and the natural frequency of the system must always be greater than the square root of two; and as the ratio assumes values greater than the square root of two, the system becomes progressively more efficient. Conversely, as the ratio becomes less than the square root of two, magnification of the vibratory forces will occur, and this condition must be avoided. As the ratio approaches unity, the magnitudes of the vibratory forces are increased until at unity, where resonance occurs, they become infinite.

The container and its contents, in combination, must provide for all environments and modes of transportation in addition to the hazards peculiar to the handling of material in transit. Section 4.6 presents guidelines for the transportation and handling of dormant electronic systems.

Reference 46 provides additional details concerning container design guidelines and container qualification tests.

4.5.6 In-Storage Cyclic Inspection

Figure 4.5.6-1 from reference 1 presents a matrix that can be used to determine inspection frequency and optimize in-storage inspection coverage. The matrix includes:

(1) The most deteriorative items to the least deteriorative in terms of a total ranking factor that accounts for deterioration, complexity, cost, accessibility, and criticality.

(2) All combinations of storage and packaging conditions ranging from the most protective (containerized package and a controlled humidity environment) to the least protective (commercial package and an open area).

Application of the matrix to a given materiel item involves assigning appropriate values to each of the weight factors depicted in figure 4.5.6-1 in order to arrive at a total ranking. This ranking represents a rough measure of the overall deterioration/cost sensitivity of the item to the storage environment. The ranking is then inputted at the proper weight column of the matrix to determine inspection frequency for any desired combination of packaging and storage protection level.

For new items, the matrix allows broad tradeoffs to be made to arrive at the optimum balance of packaging, storage, and inspection requirements. Also, the combining of deterioration with cost and the other weight factors via the matrix approach allows the specification of cost-effective inspection periods. This cost-effectiveness is illustrated by considering two items where one exhibits low deterioration properties but cost and the other factors are high and the other exhibits high deterioration properties but the total of the other factors is low. A relatively low cost or nominal test inspection frequency may be computed for both items that reflects an effective balance of all factors, whereas, if only deterioration was considered in computing the test periods, over-inspection (excessive cost) of the high deterioration item and under-inspection (low readiness assurance) of the low deterioration items would most likely result. For those items where all factors including deterioration and cost are high, frequent inspection would be required to assure materiel readiness, and for those items where deterioration and the other factors are low less frequent inspections would be required.

STORAGE PROTECTION ↓ / MATERIAL WEIGHT FACTOR →		0-1	2-3	4-5	6-7	8-10	11-12
STORAGE ENVIRONMENT	PACKING LEVEL	6	6	6	5	3	2
CONTROLLED HUMIDITY	CONTAINERIZED	6	6	6	5	3	2
HEATED	CONTAINERIZED	6	6	6	5	3	2
UNHEATED	CONTAINERIZED	6	6	6	5	3	2
SHED	CONTAINERIZED	6	6	6	5	3	2
OPEN	CONTAINERIZED	6	6	6	5	3	2
CONTROLLED HUMIDITY	"A" MAX. MIL.	6	6	6	5	3	2
HEATED	"A" MAX. MIL.	6	6	5	4	2	2
CONTROLLED HUMIDITY	"B" MIN. MIL.	6	6	5	4	2	2
UNHEATED	"A" MAX. MIL.	6	5	4	3	2	1
HEATED	"B" MIN. MIL.	6	5	4	3	2	1
CONTROLLED HUMIDITY	COMMERCIAL	6	5	4	3	2	1
SHED	"A" MAX. MIL.	6	5	3	3	2	1
UNHEATED	"B" MIN. MIL.	6	5	3	3	2	1
HEATED	COMMERCIAL	6	5	3	3	2	1
OPEN	"A" MAX. MIL	6	4	2	2	1	1
SHED	"B" MIN. MIL	6	4	2	2	1	1
UNHEATED	COMMERCIAL	6	4	2	2	1	1
OPEN	"B" MIN. MIL	6	4	2	2	1	1
SHED	COMMERCIAL	6	3	2	2	1	1
OPEN	COMMERCIAL	6	3	2	2	1	1

	WEIGHT FACTOR
DETERIORATION	
LOW	0
MODERATE	1
HIGH	2
COMPLEXITY	
LOW	0
HIGH	1
ITEM COST	
LOW	0
MEDIUM	1
HIGH	2
ACCESSIBILITY (IMPACT ON SYSTEM REPAIR TIME)	
- NO MAJOR EFFECT, SIMPLE SUBSTITUTION OF REPLACEABLE ITEM (I.E. EASILY ACCESSIBLE)	0
- NOT READILY ACCESSIBLE, REPAIR TIME INVOLVED, REQUIRES SOME SYSTEM TEARDOWN	1
- NOT ACCESSIBLE, REPAIR TIME IS SUBSTANTIAL, REQUIRES MAJOR SYSTEM TEARDOWN	2
CRITICALITY	
LOW	0
MEDIUM	2
HIGH	5

TEST FREQUENCY	
6 Months	-1
12 Months	-2
24 Months	-3
30 Months	-4
60 Months	-5
No Test	-6

Figure 4.5.6-1. Inspection Frequency Matrix (Ref. 1)

The matrix approach also provides flexibility for regulating the number and type of items subjected to cyclic inspections by adjustment of the weight assigned to the factors that relate the materiel to the storage environment.

4.6 TRANSPORTATION AND HANDLING

Transportation and Handling guidelines for dormant systems are described in the following sections. Transportation is covered in section 4.6.1 and Handling is covered in section 4.6.2. Since virtually all equipment is non-operating during transportation and handling operations, the same guidelines that apply to the transportation and handling of normally operational systems are applicable to dormant systems as well. Where appropriate, these general guidelines are augmented with additional information relevant to dormant systems.

4.6.1 Transportation

This section describes various transport types, their capacity, and their limitations. It describes the transportation environment as it affects the transportation of dormant systems, and provides guidelines for protection of dormant systems during transportation. Table 4.6.1-1 summarizes the most significant environmental factors experienced during transporation for the various transport types.

4.6.1.1 Transportation Equipment, Capacity, and Limitations

There are four major types of transportation: truck transport, rail transport, air transport, and sea transport. Each transport type imposes specific limitations to the shipment. These are primarily restrictive to size and weight of the shipment. In addition, legal limitations are imposed on shipments by the regulatory agencies of the individual states, Federal government agencies, and by foreign governments in international shipments.

4.6.1.1.1 Truck Transport

Regulations restricting the size and weight of loads that can be legally transported on the highways in the United States are determined by the individual states. Although these limitations can be exceeded if permission is obtained, it causes a considerable increase in transit time and transportation cost, and requires special permits, special routing, etc. The principal limitations imposed when shipping by highway arise from three sources:

1. Limits imposed on size and weight of loads by various state governments.

2. Limits imposed on size and wight of loads by foreign governments.

3. Limits imposed by interior dimensions of the vehicles.

Table 4.6.1-1. Relationships Between Transport Modes and the Environment Experienced by Materiel. (Ref. 64.)

Transport Type	Environmental Exposure	Most Significant Elements
<u>Truck</u>		
Open	1. Ambient climatic and natural factors	1. Temperature, humidity, solar radiation, rain, solid precipitants, natural wind, and induced wind
	2. Low to high level shock and vibration	2. Terrain (road surfaces)
	3. Sand and dust	3. Terrain, wind
Closed	1. Modified climatic and natural factors (can intensify or reduce effect of certain factors)	1. Temperature, solar radiation, humidity
	2. Low to high level shock and vibration	2. Terrain (road surfaces)
<u>Rail</u>		
Open	1. Ambient climatic and natural factors	1. Temperature, humidity, solar radiation, rain, solid precipitants, natural wind, and induced wind
	2. High level shock	2. Switching operation (humping), run-in and run-out
	3. Sand and dust (less severe than for open truck because vehicle induces far less airborne sand and dust)	3. Wind, terrain

Table 4.6.1-1 Relationships Between Transport Modes and the Environment Experienced by Materiel. (Ref. 64.) (Continued)

Transport Type	Environmental Exposure	Most Significant Elements
Rail (Continued)		
Closed	1. Modified climatic and natural factors (can intensify or reduce effect of certain factors)	1. Temperature, solar radiation, humidity
	2. High level shock	2. Switching operation (humping), run-in and run-out
Ship		
Above decks	1. Ambient climatic and natural factors	1. Salt water, salt spray, salt, fog, humidity, temperature, solar radiation, rain, solid precipitation
	2. Shock, vibration, and acceleration significantly less than for rail or truck	2. Wave impact, drive train vibration, gun fire
Below decks	1. Modified ambient climatic and natural factors	1. Humidity, temperature, solar radiation macrobiological organisms, microbiological organisms
	2. Shock, vibration, and acceleration significantly less than for rail or truck	2. Wave impact, drive train vibration, gun fire

Table 4.6.1-1. Relationships Between Transport Modes and the Environment Experienced by Materiel. (Ref. 64.) (Continued)

Transport Type	Environmental Exposure	Most Significant Elements
<u>Air</u>		
Exterior Transportation	1. Ambient climatic and natural factors	1. Low temperature, pressure, fluctuation (altitude), rain, solid precipitation, induced wind, temperature, shock, solar radiation
	2. Shock, vibration, and acceleration	2. Structurally transmitted shock and vibration, resulting from landing, maneuvers, aerodynamic forces, aircraft components
	3. Sand and dust	3. Helicopter rotor wash, aircraft prop wash, jet engine exhaust
Interior Transport	1. Modified ambient climatic and natural factors	1. Low temperature, pressure fluctuation (altitude), temperature shock
	2. Shock, vibration, acceleration	2. Structurally transmitted shock and vibration, resulting from landing, maneuvers, aerodynamic forces, aircraft components

Because of the many different regulations, there is no one unitized group of restrictions that can be followed in each case. For the United States alone, there are 51 different jurisdictions, many of which change their regulations frequently. In addition, shipments destined for overseas must meet the regulations of the countries through which they pass. (Ref. 54). For the most current information, the transportation department of the appropriate jurisdiction(s) should be contacted.

In addition to the restrictions on weight, the limits placed on the vehicle dimensions must also be considered. The shipping container should be designed to permit versatility of transport through any state without having to obtain special permits, routing, etc. The transportation department of the appropriate jurisdiction(s) should also be contacted for the maximum width and height requirements for over-the-road equipment.

In a similar manner, consideration must be given to the interior dimensions of the military vehicles that may be used to transport the material. Dimensions of standard military vehicles are listed in TM9-236, Military Tactical Vehicles.

4.6.1.1.2 Rail Transport

The principal limitations imposed on shipments by rail result from three causes:

1. Limits imposed by dimension of railroad cars.

2. Limits imposed by dimensions of the right-of-way.

3. Limits imposed by the weight and distribution of the load.

The dimensions of railroad cars in use throughout the world vary widely. The Official Railway Register (Ref. 55) lists all railroad cars used. When the shipment must also travel in foreign countries, the more restrictive limitations of these countries must be taken into consideration.

The most frequently used railroad car on the railroads of North America is the closed car, in particular the Class X box car. Material too large to fit into the closed car is carried on open cars, either a gondola car, a flat car, or a depressed-center flat car.

To promote maximum efficiency of railroad transportation, loaded railroad cars should be within the clearance limitations of the right-of-way over which the shipment will travel. The types of physical barriers which determine right-of-way clearance limits are bridges, tunnels, telephone poles, etc., which are subject to seasonal variations. If a load exceeds the limitations, a special routing must be established for the shipment. This adds enormously to the transportation cost and time. A complete listing of clearances for most world railways is given in World Railways, Sampson Lows, Publisher, London, England.

The total load that may be carried by a railroad car is restricted by the weight limit of the car, and by the load limits of the rail bed, bridges, etc., over which the shipment will travel. When the load approaches the specified limits, the local freight agent should be consulted to ensure that the shipment can be efficiently transported by the carrier.

4.6.1.1.3 Air Transport

Shipments by air transport are subject to the limitations imposed by the characteristics of the aircraft used for the shipment. The principal limitations are as follows:

1. Limits imposed by maximum aircraft payload.

2. Limits imposed by size, location, and configuration of door openings, including limitations caused by the use of ramps for loading.

3. Limits imposed by the size and configuration of cargo compartments including limiting factors that may prevent full utilization of available space.

4. Limits imposed by quantity, location, and strength of tiedown fittings.

6. Limits imposed by the aircraft center of gravity limits forward and aft.

7. Limits imposed by altitude and temperature changes, especially in unpressurized cargo compartments.

8. Limits imposed by restricted cargo.

Maximum dimensions for transportability in US Air Force aircraft are defined in reference 54.

4.6.1.1.4 Sea Transport

Sea Transport is capable of carrying any shipment that can be transported to dockside and loaded on board ship. Generally, on-deck stowage is limited only by the capacity of the deck, and maximum weight limitations. Below-deck stowage adds additional limitations.

While special handling equipment can be made to load any given weight a ship can carry, the weight of individual containers should be limited to the boom capacity of the vessel to permit loading and unloading without the use of shore equipment. Since all cargo ships are equipped with at least a 5-long-ton (2240 pounds) boom, an 11,200-pound load can be loaded and unloaded anywhere by any type of vessel. If the container includes an explosive material, such as a complete missile with a high-explosive warhead and a solid or liquid propellant motor, a Coast Guard weight limitation of 7467 pounds must be observed if the material is to be capable of being loaded and unloaded anywhere by any type of vessel.

The limitations imposed by each ship varies widely; however, for easy stowage in most vessels, the container dimensions should not exceed 35 feet in length, 20 feet in width, and 11 feet, 4 inches in height. A height of 6 feet 1--1/2 inches has been determined as being optimum.

4.6.1.1.5 Combination Transport

When weapon systems are shipped for long distances, and to overseas destinations, a combination of different types of transport is required. For shipments using several types of transport, three methods of combination transport were developed.

These method are:

1. Roll-On/Roll-Off systems for truck-sea combination.

2. Trailer-On-Flat-Car system for truck-rail combination.

3. Trailer-Containers-on-Flat-Car system for truck-rail-sea combination.

Combination transport provides the economy of a cost-effective use of transport types, and eliminates the cost and the inherent risks in excessive material handling. This is especially important for dormant systems since failures which occur as a result of transportation and handling may not be detected for long periods of time. However, the most restrictive limitations imposed by any of the transport types used in combination transport will apply, and must be considered as a factor in the system and container design.

4.6.1.2 Transportation Environment

The transportation environment consists of the conditions and forces to which material are subjected during transportation. This includes both normal operations and accident conditions, and consist, essentially, of the following elements:

1. Shock and Vibration.

2. Terminal handling for truck, rail, air,and sea transportation.

3. Varying atmospheric pressures normal to each mode of transportation.

4. Accidents.

5. Temperature and humidity variations normal to each mode of transportation because of equipment or operating environment.

6. The world-wide weather environment in terms of temperature, atmospheric pressure, and humidity.

7. Critical physical and geometric limitations.

8. Forces causing puncture and abrasion.

The elements of shock and vibration experienced during transportation are described in the following paragraphs. Other environmental factors are discussed in section 3 of this report.

The most damaging element encountered by a shipment is shock and vibration. The shock and vibration to be expected depends on the mode of transportation, and is further dependent upon the manner in which the material is packaged and stowed. The techniques used for protecting packaged material against the harmful effects of shock and vibration include blocking and bracing, use of cushioning material, and use of shock and vibration isolation systems.

Although shock and vibration are often treated as separate phenomena, the distinction between the two is not clear cut. The difference between transient shock motion and periodic vibration is fairly obvious; but the existence of any basic differences between shock and random vibration, which is not periodic, is much less obvious. However, shock may be considered as intermittent excitation and vibration as sustained excitation.

Vibrations and shocks will impose forces on, and deform, any flexible or elastic structure. The severity of the deformation depends upon the nature of the imposed force, and the geometrical configuration, total mass, internal mass distribution, stiffness distribution, and damping of the item or equipment.

Vibration is an oscillation wherein the quantity is a parameter that defines the motion of a mechanical system. Vibration has also been described as the variation, usually with time ,of the magnitude of a quantity with respect to a specified reference, when the magnitude is alternately greater and smaller than the reference. Vibration may be periodic in nature, or it may be non-periodic.

The simplest form of periodic vibration is simple harmonic motion, which is motion that varies sinusoidally. Simple harmonic motion can be identified by any two of the four parameters: frequency, amplitude of excursion, velocity, and acceleration. Any periodic motion can be considered as consisting of motions at one or more frequencies, with the motion at each frequency being harmonic. A periodic, or steady-state, vibration can be completely defined by designation of the frequency or frequencies, the maximum value of the harmonic variable at each frequency, and the phase relationships that exist between the component harmonic motions. The harmonic variable may be expressed in terms of displacement, velocity, or acceleration.

There are two types of non-periodic vibration: random and white-noise. Random vibration differs from periodic vibration in that the amplitudes at the component frequencies vary randomly with respect to time, and therefore cannot be predicted. White-noise vibration has no defined component frequencies, and both its frequencies and amplitudes may vary randomly with time.

The response of a structure to shock and vibration is determined largely by the excitation frequency and the resonance characteristics of the structure. Resonance affects the magnitude of of the applied load and its transmission characteristics. Any shock or vibration at the resonant frequency is amplified in force, resulting in an increased chance for damage.

1 e ratio of the output vibration amplitude to the applied vibration is the transmissibility. Transmissibility can be considered a magnification factor, and is greatest at resonance. It decreases down to unity below resonance, and can become less than unity above resonance.

Shock connotes impact, collision, or blow, usually by physical contact. It denotes a rapid change of load, or a rapid change of acceleration with a resultant change of load. A shock motion cannot be defined by assigning numerical values to established parameters; it can only be defined by describing the history of a significant parameter such as acceleration, velocity, or displacement. The time duration of a shock pulse is important, since it helps in determining the way which an object will react to that pulse.

Actual shock and vibration likely to be encountered varies for the four major types of transport. Shock and vibrations in truck transport are generated through normal highway operation, starting and stopping movements, acceleration and deceleration, coupling and uncoupling, docking, and additionally such minor accidents as sideswipes, rear-end collisions, etc. Vibration frequencies in motor trucks are dependent upon the natural frequency of the unsprung mass on the tires, the natural frequency of the spring system, and the natural frequencies of the body structure. The vibration amplitudes are dependent upon road conditions and the speed of travel. Intermittent road shocks of high magnitude can occur, with resultant extreme truck-body displacements. These large displacements may result in a severe shock environment for unlashed cargo as it bounces about the truck floor. Vibrations caused by the truck engine are relatively insignificant in the cargo area. The predominant natural frequencies of various commercial vehicles can be obtained in reference 56.

Shock and vibration effects in rail transport are generated through normal operational conditions including end shock caused by switching and humping operations, longitudinal shock caused by slack conditions in over the road operations, and vertical and lateral vibrations also caused by over-the-road operations. Vibrations in moving freight cars arise from track and wheel irregularities, and occur principally in the lateral and vertical directions. The exciting frequencies caused by rail joints and wheel imbalance vary from 0 to 13 Hertz per second. Railroad car structural-frame frequency is usually in the range of 55 to 60 Hertz. Shock and transient vibrations during coupling and during starting and stopping are generally considered to be the most damaging phases of rail shipment. The mean speed of impact is about 7 miles per hour, which is well above the approximate 5 miles per hour limit for which the switching gear provides cushioning protection.

Shock and vibration effects in air transport are generated through normal operational conditions in flight, and during take-off and landing. In-flight vibrations are of two types: mechanical and acoustical. Acceleration stresses from sharp-edged gusts and boosts tend to supplement vibration stresses. The largest single source of vibration appears to be the propulsion system. Self-excited vibration is caused primarily by flutter, the vibration of lifting, and transitory loads to the aircraft. This is most evident in taxiing, take-off and landing, and in abrupt maneuvers. Forced mechanical vibrations result primarily from the mechanical forces. The in-flight shock and vibration environment is generally not too severe. The loadings which are important are the dynamic loadings that occur during flight in rough air. These are differentiated from shock loadings in that they consist of fairly high magnitude accelerations imposed for a prolonged period of time. These accelerations can be as high as 2 to 3 g's during normal operation of large transport aircraft.

In ship transport, the principal excitation forces for shipboard vibrations result from the ship structure interfering with the flow of water, from the propellers, and from imbalance or misalignment of the propeller shaft system. The frequency range of the vibrations is about 5 to 25 Hertz, with attendant acceleration reaching a maximum of amount 1g. During normal service, ship cargo do not experience shock loads of any significant magnitude.

Detailed specifications for and information on shock and vibration are given in MIL-STD-810, MIL-P-116, MIL-STD-648, FED-STD-101, MIL-S-901, and MIL-STD-1670.

Detailed specifications for and information on package cushion design to mitigate the effects of shock and vibration in equipment design can be found in MIL-HDBK-304.

4.6.1.3 Protection During Transportation

Systems can be protected during transportation by the following methods:

1. Design of the system.

2. Design of the transport vehicle.

3. Packaging of the system.

4. Shoring, bracing, and tie-down of the system.

5. A combination of these methods.

Design guidelines to protect a system from various dormant environments are found in sections 3, 4.1, and 4.5 of this report. The following engineering design parameters for transportability of military material were developed by the Department of the Army, and are provided as design guidelines. (Ref. 48)

1. Truck Transport - For truck transport, the cargo and its restraining system should be capable of sustaining the loadings incident to a 1,000 mile road trip over a paved highway. For all shocks and vibrations, the stresses in the restraining system should not exceed the yield strength of the material, nor should they exceed one-half the yield strength of the material under static load conditions.

   Envelopes of maximum values recorded during Transportation Corps field studies for both shock and vibration are provided in MIL-HDBK-409. It is recommended that the vibration time for design purposes be consistent with a 5,000 mile trip and that design safety factors, if any, be applied by increasing the time of vibration. For design purposes, it is recommended that the restraining items be designed to withstand 30 shock applications.

2. Rail Transport - For rail transport, the cargo and its restraining systems should be capable of withstanding a simulated transportation shock environment as described in MIL-STD-810.

   The stresses in the restraining members should be less than one-half the yield strength of the material in the static, or restrained condition. The combined static and dynamic stresses must not exceed the static yield strength of the material in any restraining system component during the dynamic portion of the impact loading. Additional margins of safety may be required during design of the restraining systems because of the cargo's peculiar nature, train safety considerations, or accident effects considerations.

   The cargo and its restraining system should be able to withstand without failure or impending failure, a transportation vibration environment equivalent to one produced by over-the-road movement in a 150-car train. The car transporting the cargo should have standard freight car suspension and draft gear, and should be considered for the end of the train car position. Vibrations, both intermittent and continuous, should be of a duration equivalent to the input from 3,000 miles of Class I railroads containing at least 50 percent long maximum grades.

3. Air Transport - Induced shock and vibration environments for air transport are normally considered the least severe as regards loading of the cargo and its restraining system. Factors of aircraft safety, cost of cargo, and military value of the cargo dictate the highest degree of reliability for the strength of the cargo and its restraining systems. Many strength and safety

factors are employed both in design and operation for restraining systems involving air transport, with consequent multiplication factors applied to the basic environmental data. The basic data should be especially accurate in order to minimize cumulative error on the inaccurate portion of the data that is proportioned or multiplied for safety or design reasons.

For air transport, the cargo and its restraining system should be capable of withstanding all the aircraft vibrations occasioned from a time period consistent with the maximum range of the aircraft. It is considered important that the amplitude and frequency of the vibration be accurately duplicated and that safety factors be applied in terms of the length of the vibration. It is recommended that the restraining system be designed to sustain the vibration for a period three times as long as would be anticipated based on the mission of the aircraft.

The shock acceleration normally occasioned by landing should be based on a velocity at touchdown for the aircraft of 10 feet per second. Again, any safety factors should be applied by increasing the number of shocks rather than the severity. It is recommended that the restraining system be capable of withstanding 20 landing shocks with no signs of failure or impending failure to any of the components.

4. Sea Transport - For sea transport, cargo and its restraining system should be capable of sustaining an environment occasioned by a seaway induced loading of a transport ship consequent to 20 days of Beaufort Sea State Condition 12. During this condition, the components of the restraining system should not exhibit a combined static and dynamic stress in excess of 80 percent of the static yield strength of the materials. The static stresses occasioned by normal tiedown procedures should not exceed 50 percent of the static yield strength of the materials.

Particular emphasis must be placed on the effects of stacking cargo for shipboard transport. Stacking may subject the cargo, the cargo container, or the restraining system to severe loading conditions. As the dynamic and static loads are resisted by each succeeding lower unit of cargo in the stack, the cumulative effect on the bottom units must be considered in design. The same consideration as regards stacking and dynamic loading must be given in the horizontal plane since longitude accelerations will also cause a load buildup on the end unit unless load dividing measures are taken. Effects of cargo stacking are most troublesome in sea transport because of relatively large cargo holds which accommodate excessive stacking.

While most operationally ready pieces of equipment require some sort of preparation for shipment, most dormant equipment are kept in shipping and storage containers and require relatively little preparation for shipment. Depending on the item, however, certain subassemblies may require folding, removal, or reorientation. Exposed machined metal surfaces will require a protective coating to prevent corrosion. Dissimilar metals will set up a galvanic action, and must be insulated from each other in the original design or as part of the preparation for shipment. Fuel systems may have to be drained, purged, and reserved. These features, and other similar ones should be considered when the item is designed to reduce the time required to accomplish these tasks, ease their performance, and reduce the possibility of damage. (Refs. 54 and 57)

The design of some items of material/equipment limits the points at which attachments may be placed for lifting and tieing down. Certain tiedown practices may cause extensive damage to the item. Therefore, consideration should be given to the design, location, and marking of attachments for lifting, ground handling, and restraining for surface and air transportation. MIL-STD-209 provides guidance for the design and location of lifting and tiedown provisions. All devices used as hoist or lift equipment for hazardous materials should have an allowable design stress below one-fifth the yield stress of the material. (Ref. 54)

Restraint criteria should be met for all applicable modes of shipment. MIL-STD-209, MIL-STD-814, MIL-A-8421, and Air Force System Command (AFSC) Design Handbook (DH) 1-11, Air Transportability, provide appropriate guidance for restraint of cargo. However, the designer should consider also the tiedowns and any other appurtenances or possible attachment points, from the viewpoint of the person charged with moving the item, to determine how an inexperienced person would restrain it. Parts of the item that could be damaged if they are used as restraining points should be marked to preclude improper use, and suitable parts should be marked for use as restraining points. Typical lifting and tiedown provisions for various military vehicles are presented in MIL-HDBK-151.

4.6.2 Handling

This section presents guidelines for providing protection for systems during handling. It presents various types of material handling equipment and systems and their limitations. Handling methods and human factors considerations are also presented. Handling of systems occurs throughout all phases of transportation and storage. The designer should consider the limitations of existing handling equipment concurrently with the development of the material and its containers. If required, special handling equipment should also be developed concurrently, although the use of specialized equipment should be kept to a minimum.

4.6.2.1 Handling Equipment, Capacity, and Limitations

The design and specification of handling methods is an essential part of planning for the protection of all systems during handling. This is especially true for dormant systems since many of the failures reported for these systems are induced by operator or maintenance handling and such failures may go undetected for long periods of time. Generally, specific instructions are required for each system. The extent of detail required depends primarily on the size and complexity of the system, and the quantity of special equipment used in material handling.

The various types of material handling equipment that may be used at various cargo handling and storage installations include the following:

1. Powered self-propelled equipment consisting of forklift trucks, wheeled warehouse tractors, warehouse cranes, hand-lift pallet trucks, fixed platform trucks, straddle-carry trucks, overhead and gantry cranes, and hoists.

2. Nonpowered mobile equipment consisting of platform warehouse trailers, hand trucks, and dolly trucks.

3. Conveyors, including portable belt-types, roller gravity and wheel gravity types.

4. Pallets made of wood or metal.

5. Hoisting slings and spreaders, hoisting beams, and hoisting bars.

The design engineer should ensure that the packaged material can be handled by standard handling equipment. If necessary, several equipment units may be used to lift extremely long or heavy containers. The container should be clearly marked showing the handling locations, such as lifting eyes, rings, handles, brackets, and center of balance. Lifting eyes should be permanently attached and large enough to accept rigging cable hooks. They should also be far enough above the center of gravity of the container to stabilize it. Handles should be so positioned that they will not catch on other units, cables, lines, structural members, etc.

If the container is too awkward or heavy for manual lifting, some method of mechanical handling must be provided. To permit handling by forklift trucks, the bottom of the container should be raised three inches above the ground. This is usually accomplished through the use of skids spaced to allow for the entry of forklift tines. Reinforced channels should be constructed at the bottom of the container to prevent the fork times from damaging the container wall. Two fittings should be located at the end of the container, adjacent to the skids, for use in moving the container. Various standard types of powered and no-powered handling equipment and conveyors for use by all military services are illustrated and described in TM-743-200 (Ref. 58).

MIL-STD-137 (Ref. 59) specifies the standard handling equipment normally required for specific loading and unloading operations.

Various types of pallets are used in the handling of material, including general purpose and special design pallets. Generally, where possible, material should be palletized in a unit load for shipment and storage. MIL-STD-147 (Ref. 60) provides the practices and procedures to be followed in palletizing or containerizing unit loads, which are mandatory for use by all department and agencies of the Department of Defense.

4.6.2.2 Human Factors Considerations

Human factors considerations should be recognized by the design engineer as being a necessary part of the planning of the handling process. Human engineering principles and criteria should be applied together with other design requirements to identify and select the equipment to be operated, maintained, and controlled by man. Essentially, this effort should ensure that the human functions and tasks are organized and sequenced for efficiency, safety, and reliability. Appropriate training and technical publications should be provided, as required.

Specifications for and information on human engineering requirements can be found in MIL-H-46855 (Ref. 61), MIL-STD-1472 (Ref. 62), and MIL-HDBK-759 (Ref. 63).

4.7 REFERENCES

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5.0 EVALUATION METHODS

5.1 INTRODUCTION

Military electronic systems must be evaluated throughout their design, development, production, and deployment to ensure that they meet all performance requirements, such as functional performance, reliability, maintainability, availability, useful life, etc. This is especially true for systems that will spend a significant part of their service life cycles in non-operating states since such evaluations are often the only means available for determining the integrity of these systems. The following sections present evaluation methods that have been found to be useful in evaluating systems of this type. Section 5.2 discusses in-plant evaluation methods and section 5.3 discusses evaluation methods useful in a field environment. Special evaluation methods are covered in section 5.4. Additional information concerning evaluation methods for dormant systems is available in Reference 6.

5.2 IN-PLANT EVALUATION METHODS

In-plant evaluation methods are comprised of the many analyses and tests that electronic equipment are subjected to during design, development, and production to ensure that all performance requirements are met once they are fielded. Many of these analyses and tests are the same regardless of the amount of time that the fielded equipment will spend in a non-operating state. This section covers several in-plant evaluation methods that are either significantly affected by equipment non-operating periods or have been useful in testing and evaluating systems that will spend a significant amount of time in non-operating states. Section 5.2.1 covers worst case circuit tolerance analysis and discusses the need to consider the impact of long-term non-operating periods. Section 5.2.2 covers a method for performing reliability assessments considering both the operating and non-operating periods throughout an equipment's life cycle. Accelerated life testing as a method for evaluating the impact of long-term operating and non-operating periods is discussed in section 5.2.3. Finally, environmental stress screening is discussed in section 5.2.4.

5.2.1 Worst Case Circuit Tolerance Analysis (Ref. 1)

All circuits are required to function properly and to the requirements of the applicable specification under their worst-case conditions. These worst-case conditions include not only electrical parameters, but environmental factors, packaging factors, noise, aging, storage, and other factors as well. Worst case (circuit tolerance) analysis ensures that the end product will have the capability to satisfy all functional requirements, within the required performance and safety margins, under the most unfavorable combination of realizable conditions.

Three types of analysis are performed: d.c., a.c., and transient. Worst-case d.c. analysis is accomplished by calculating the d.c. current and voltage levels which exist at each node of a given circuit under worst-case conditions. The final output as a function of the input will then yield the d.c. transfer characteristics to be compared to the design requirements. Worst-case a.c. analysis is accomplished by calculating the a.c. current and voltage levels which exist at each node of a given circuit under worst-case steady-state conditions. The final output as a function of the input yields the a.c. transfer function which is then evaluated for discrepancies in characteristics such as magnitude, phase shift, and propagation delay versus frequency. Worst-case transient analysis is accomplished by calculating the effects, at various nodes, of worst-case transients resulting from worst-case transient (step) functions at the various inputs and at other nodes of the circuits where electromagnetic interference and/or cross-talk can occur. Worst-case transient analysis is also performed to determine the effects of worst-case shock, nuclear, and other environments.

To perform the worst-case analysis, three analytical techniques have been developed:

1. Absolute Worst Case - Circuit is evaluated to determine if it meets all performance requirements with all components degraded to their end-of-life tolerance in the worst direction.

2. Taylor Worst Case - Circuit is evaluated to determine if it meets all performance requirements with all components at their worst initial (purchase) tolerance and with any one component part at its end-of-life tolerance.

3. Modified Taylor Worst Case - Circuit is evaluated to determine if it meets all performance requirements with all components at their nominal values and with any one component at its worst end-of-life tolerance.

As a minimum, the Modified Taylor Worst Case analysis should be applied to linear analog circuits. For digital circuits and analog feedback circuits, the Absolute Worst Case or Taylor Worst Case analysis should be applied. In addition, the Taylor Worst Case and Modified Taylor Worst Case analyses should be applied to each component whose parameter variations have, as indicated by a sensitivity analysis or engineering judgement, a significant effect on circuit operation.

In addition to these analysis techniques, computerized methods such as ECAP (Electronic Circuit Analysis Program) and SCEPTRE (Systems for Circuit Evaluation and Prediction of Transient Radiation Effects) can also be employed. The important consideration for dormant systems is that parameter drift and device degradation during dormant periods over the life of the system be considered in the analysis.

When performing the worst-case analysis, the following procedures should be followed:

1. Define the circuit performance requirements.

2. Generate analytical models for each circuit to be analyzed.

3. Determine the worst-case tolerances of the independent variables (i.e., part parameters, supply voltages, interface impedances, electro-magnetic interference, cross-talk, temperature, input signals, noise, etc., including end-of-life end-point values) which appear in the analytical models.

4. Determine additional effects to the various independent variables due to the various environments of nuclear attack, long term storage, transportation and handling, etc. These environmental considerations should include shock, vibration, humidity, temperature, gamma rays, x-rays, neutrons, beta rays, etc.

5. Using the worst-case tolerances of the independent variables, solve the analytical models for the minimum and maximum values of the circuit dependent variables (i.e., voltages, currents, dissipations, output requirements, etc.)

6. Compare worst-case minimum and maximum values of dependent variables with design requirements.

7. Note all circuits which will not meet their performance requirements under any set of required worst-case conditions along with recommendations of appropriate corrective action. When possible, an analysis of the probability and/or duration of these circuit malfunctions should also be made.

The following precautions should be observed when performing the analyses:

1. Input and output loading at each circuit should be strictly accounted for.

2. Stray effects of special circuit-interfaces developed for ease of analysis should be delineated.

3. All assumptions regarding the circuit should be noted in the analysis.

4. The effects of noise, electro-magnetic interference, and cross-talk should be considered. Nuclear environments should be considered, where applicable.

5. Worst-case analyses should be sufficiently generalized to show that entire circuits and combinations of circuits will perform their required functions under worst-case conditions.

6. Analyses may be necessary both for the individual circuits and for various groupings of the same circuits in order to show that the subsystems will meet design requirements.

7. Temperature ranges assumed for various parts and elements during operating and non-operating periods should be in agreement with the results of any thermal stress analyses performed.

8. Traceability must be maintained in the performance of the analysis to permit any reviewer to readily follow the calculations and rationales, and to allow for ease of updating of the analysis as data or requirements change.

5.2.2 Life Cycle Reliability Assessment

A comprehensive life cycle reliability assessment requires the consideration of all possible states and the time in each state that an equipment must survive. While most contractual reliability requirements are given in operational terms, the performance of electronic equipment depends on the effects of other life cycle states such as transportation, testing, equipment power on-off cycling, and non-operation.

Reference 2 provides an eight part procedure for developing a comprehensive life cycle reliability assessment. The eight steps are as follows: (Ref. 2)

1. Define the mission profile.

2. Determine the use scenario.

3. Determine component operating failure rates.

4. Determine equipment operating failure rates.

5. Determine component non-operating failure rates.

6. Determine equipment non-operating failure rates.

7. Compute the average service life failure rate.

8. Compute the reliability.

Step 1, the definition of the mission profile, is the initial phase of any reliability assessment process. During the mission profile definition process, specific time intervals and stresses that the equipment will experience in every operating environment must be defined.

The use scenario, step 2, considers the mission profile defined in step 1 plus the non-operating time between missions. In addition to the operating environment information provided from the mission profile, specific time intervals and stresses encountered during the non-operating phases of the use scenario are defined.

Steps 3 and 4 are well defined in MIL-STD-785 (Ref. 3) and MIL-HDBK-217 (Ref. 4). Steps 5 and 6 represent the corresponding reliability assessment tasks for non-operating periods based upon the use scenario and are fully covered in References 2 and 5. Steps 3 through 6 yield two unique parameters characterizing equipment reliability: the inherent equipment operating failure rate and the inherent non-operating failure rate.

In step 7, the average service life failure rate, which is defined as the number of failures per unit time regardless of operational mode, is computed. It is dependent upon the operating failure rate, non-operating failure rate, operating duty cycle, and non-operating duty cycle and is represented by the following equation for a scenario of one operating state and one non-operating state: (Ref. 2)

$$\lambda_{SL} = \lambda_O(t_O/(t_O + t_N)) + \lambda_N(t_N/(t_O + t_N))$$

where,

λ_{SL} = service life failure rate

λ_O = equipment operating failure rate

λ_N = equipment non-operating failure rate

t_O = one mission operating time

t_N = non-operating time between missions

While this equation will become more complex as the number of operating and non-operating states increases, it will take the same general form. The service life failure rate is one of the most informative comprehensive reliability parameters. (Ref. 2) It is constant with time and is therefore useful for comparing or evaluating the total reliability for equipments with an indeterminate mission duration. This is extremely important since, as demonstrated by E. Demko (Ref. 7), using only the total number of failures and the total operating time will give the appearance of a changing failure rate due to the statistical effect caused by a changing usage profile. The service life failure rate also provides a good indication of the reliability of equipments which are exposed to intermediate amounts of both operating and non-operating periods, and for equipments with a use scenario dominated by non-operating periods, it approximates the dormant equipment failure rate.

The $(t_O/(t_O + t_N))$ term represents the operating duty cycle, and the $(t_N/(t_O + t_N))$ term represents the non-operting duty cycle. In cases where there is no definitive service life time interval $(t_O + t_N)$, estimates can often be made of the respective duty cycles. The service life failure rate could then be computed with appropriate duty cycle values rather than specific values for t_O and t_N.

Given the time intervals defined during the definition of the use scenario, the equipment reliability is given as:

$$R = e^{(-(\Sigma \lambda_{Oi} t_{Oi} + \Sigma \lambda_{Ni} t_{Ni}))}$$

where,

R = reliability

λ_{Oi} = operating failure rate in the i^{TH} operating state

t_{Oi} = time in the i^{TH} operating state

λ_{Ni} = non-operating failure rate in the i^{TH} non-operating state

t_{Ni} = time in the i^{TH} non-operating state

This model assumes a "wooden round" maintenance concept (i.e. no test or repair prior to use.). Adjustments to this model that are necessary to account for the impact on reliability of a periodic monitoring/repair maintenance philosophy are described in section 4.3.

When using this procedure, it must be understood that the use of handbook derived component failure rates to calculate the service life failure rate and equipment reliability limits the usefulness of these parameters to relative comparisons among competing designs. It is inappropriate to use these parameters so derived as absolute measures of equipment performance in an actual use environment. If absolute measures are required, the assessments should be based upon test data or actual field experience for the equipment in question. These topics are covered in succeeding sections. For additional information on methods for assessing dormant system reliability, the reader should refer to Reference 6.

5.2.3 Accelerated Life Testing

Accelerated life testing (ALT) is a technique often used to predict the lifetime of electrical or mechanical components in an intended usage environment or to obtain failure rate data in a relatively short period of time. This is accomplished by subjecting items to above normal stresses over a short time period in order to simulate the effect of normal stresses over a much longer time period. It requires a knowledge of the predominant failure mode under rated stress conditions, the environment which excites the failure mode, and a quantitative relationship between the stress level and the failure occurrence or material deterioration rate. Once this relationship is determined, it can be used to estimate the failure rate or aging behavior within the usage environment of interest.

ALT is a very effective method of reducing the time required to accomplish the magnitude of testing necessary to provide a statistically significant measure of reliability on low failure rate items. It is therefore suitable for evaluating dormant systems since they typically have very long lifetimes (often 20 or more years) and low failure rates due to reduced stresses during non-operating periods.

ALT is most effective when applied at the component level rather than at higher levels of assembly. The foremost problem in applying ALT at any level is the determination of the acceleration factor. Acceleration factors have been validated at the component level by testing at various stress levels. At higher levels of assembly, however, the validation of acceleration factors is very difficult, if not impossible, to achieve. The excitation of failure mechanisms at higher assembly levels is also a problem. Since individual components are likely to be sensitive to different stresses, it is not reasonable to expect that a single stress could be chosen to provide an accelerated test.

The two most common methods of accelerated aging are referred to as time-compression techniques and over-stress techniques. (Ref. 9) In time-compression techniques, the rate of cycling of an environmental variable (e.g. shock, vibration, power on-off cycling, etc.) that is cycled during the component's lifetime is increased. It is an appropriate accelerated aging technique as long as the cycled variable is the sole cause of the failure mode and if the failure depends on the number of cycles but not on the rate of cycling.

Over-stress techniques involve increasing an environmental variable above its ambient value in order to accelerate the aging process. Several models relating aging to stress have become well established and are used frequently in applying the over-stress technique. These models are: the Arrhenius Model, the Eyring Model, the Inverse Power Model, and the 10-Degree Rule.

The Arrhenius model relates the variables of time and temperature to the deterioration of materials and therefore is often used for calculating accelerated thermal aging parameters. It is usually applied in the form: (Ref. 8)

$$L = Be^{E/kT}$$

where,

L = time to reach a specified endpoint or lifetime

B = constant (usually determined experimentally)

E = activation energy (eV)

k = Boltzmann's constant (0.8617×10^{-4} eV/K)

T = absolute temperature (K)

To use the Arrhenius model for the purposes of accelerated thermal aging, the activation energy must be known. Table 5.2.3-1 lists activation energies for a number of materials and components. In applying this model it must be understood that extrapolation of the model to time periods (temperature) far exceeding the range of experimentally determined data is extremely risky, and large errors may result. (Ref. 8)

The Eyring model provides a formulation that is more thermodynamically correct than the other models and is the only one that can include additional stress terms to allow for synergistic effects. It is most difficult to apply in practical aging programs, however, because the model parameters have been determined for very few materials and components. The model takes the following general form: (Ref. 8)

$$K = K_0 e^{nS} = aT^{w}e^{-b/kT}e^{S(c + (d/kT))}$$

where,

Table 5.2.3-1. Activation Energies for Electronic Components (Ref. 8)

Component	Activ. Energy (eV)	Remarks
Capacitors, chlorinated diphenyl. No stabilizers.	1.17	DC life. Stressed at 1000 Volts per mil. See Note 1.
Capacitors, chlorinated diphenyl. 0.5% anthraquinone	1.53	DC life. Stressed at 1000 volts per mil. See Note 1.
Capacitors, chlorinated diphenyl. 0.5% azobenzene	2.00	DC life. Stressed at 1000 volts per mil. See Note 1.
Capacitors, chlorinated diphenyl Kraft paper	0.86	Dielectric stressed with dc potential, 10^6 V/in. See Note 1.
Capacitors, chlorinated diphenyl Kraft paper with 0.5% azobenzene	1.50 - 1.93	Dielectric stressed with dc potential, 10^6 V/in. See Note 1.
Capacitor, dielectric, tubular paper	2.42	10% capacitance increase. See Note 1.
Capacitors, metalized paper	1.32	Life defined as time required to regain original value of capacitance after initial increase. See Note 1.
Capacitors, titanium titanium dioxide, thin-film. @25-100 deg. C	0.09	Formed by anodization. Tests with rate of temperature rise approximately 2.5 deg. C/min.
Diodes, Si - General	1.13-2.77	
Diodes, Si (-1960)	1.14	
Diode, silicon, 1N673 and 1N696	1.8	50% failure. See Note 1.
Diodes, silicon, p-n-p-n	1.41	

Table 5.2.3-1. Activation Energies for Electronic Components (Ref. 8) (Continued)

Component	Activ. Energy (eV)	Remarks
Diodes, silicon, varactors	2.31-2.38	
Diodes, other	1.13-2.77	
Diodes, varactors	2.31-2.38	
Microcircuits, CMOS type CD4024A	1.0	25h @ 250 deg. C = 50% failure. See Note 2.
Microcircuits, CMOS type CD4013A	1.1	42h @ 250 deg. C = 50% failure. See Note 2.
Microcircuits, CMOS type CD4011A	1.4	90h @ 250 deg. C = 50% failure. See Note 2.
Microcircuits, CMOS		
4007 freak pop.	0.9	
main pop.	1.3	
Operational Amplifier 741		
-freak pop.	0.7	
-main pop.	1.6	
-mixed pop.	0.8	
-freak pop.	0.8	
-main pop. (1/2 voltage)	0.9	
Printed circuit board material (1/32 in.), NEMA G-10 and FR-4	1.05	50% retention of electrical strength. See Note 1.
Printed circuit board material (1/32 in.), NEMA G-10 and FR-4	1.49	50% retention of flexural strength. See Note 1.
Semiconductor devices, silicon	0.9-1.4	predominant value - 1.1 eV.

Table 5.2.3-1. Activation Energies for Electronic Components (Ref. 8) (Continued)

Component	Activ. Energy (eV)	Remarks
Silicon transistors and integrated circuits	1.1	Testing of transistors and integrated circuits based on Arrhenius model.
Transistors	0.66	
Transistor, Ge alloyed,		
OC 1972 (1964)	1.26	
(1966)	1.08	
Transistor, Ge alloy LT123 (1958)	1.25	
Transistor, bipolar, p-n-p-n	1.65	
Transistors, CMOS	1.18	Eyring model.
Transistor, diffused germanium	0.87	Step-stress tests without moisture moisture getter. Median life. See Note 1.
Transistor, diffused germanium	1.24	Constant stress tests with moisture moisture getter. Median life. See Note 1.
Transistor, Ge gettered	1.24	
Transistor, Ge mesa, AF106 (1969)	1.00	
Transistor, Ge mesa,		
2N559 (1958)	1.17	
(1959)	0.95	
(1960)	1.14	
Transistor, Ge MADT,		MADT = Micro alloy diffused transistor.
2N501 (1958)	1.07	
Ge MADT, 2N501 (1959)	1.07	

Table 5.2.3-1. Activation Energies for Electronic Components (Ref. 8) (Continued)

Component	Activ. Energy (eV)	Remarks
Transistor, Ge MAT 2N292 (1960)	1.0	MAT = Micro alloy transistor.
Transistor, Ge MAT 2N393 (1959)	1.0	MAT = Micro alloy transistor.
Transistor, Ge ungettered	0.88	
Transistors, germanium @ 60 deg. C	0.99-1.26	
Transistors, germanium	0.17	Near and below room temperature.
Transistors, germanium, ungettered	0.88	
Transistors, germanium, gettered with vycor or molecular sieve	1.24	
Transistor, Si mesa, 2N269 (1961)	0.38 0.58	Conditions unknown. Constant stress.
Transistor, Si mesa, 2N560 (1959) (1960)	1.12 1.50	
Transistor, Si mesa, 2N1051 (1960)	1.12	
Transistor, modern, submarine cable	1.4	
Transistors, MOS	1.2	
Transistors, MOS	1.10	Median life for failure criterion of 1.0 V shift. See Note 1.
Transistors, MOS	1.10	Median life for failure criterion of 0.5 V shift. See Note 1.

Table 5.2.3-1. Activation Energies for Electronic Components (Ref. 8) (Continued)

Component	Activ. Energy (eV)	Remarks
Transistor, power, MSC 1330	0.81	Median time to failure. See Note 1.
Transistors, Si main pop. (1960)	1.02	
Transistor, Si planar, BFY 33 (1969)	1.12	
Transistor, Si planar,		
4A-2 (1967)	1.18	Step stress.
(1967)	1.50	Constant stress.
(1963)	1.29	Constant stress.
Transistor, Si, p-n-p-n	1.65	
Transistors, Si, (All)		
-before wearout	1.12	
-at wearout	1.46	
Transistor, Si, bipolar	1.02	With surface inversion failures.
Transistor, Si, bipolar	1.02-1.04	With Au-Al bond failures.
Transistor, Si, bipolar	1.77	With metal penetration into Si.
Transistor, silicone mesa, 2N560	2.16	50% failure. See Note 1.
Transistors, Si, typical	0.96	t_{10} lifetime. See Note 1.
Transistors, Si, typical	1.11	t_{50} lifetime. See Note 1.
Transistors, submarine cable	1.30	0.025% failure. See Note 1.
Transistors, submarine cable	1.24	50% failure. See Note 1.

Table 5.2.3-1. Activation Energies for Electronic Components (Ref. 8) (Continued)

Component	Activ. Energy (eV)	Remarks
Transistors, 2N559, vacuum baked.	0.89	Me\ : life based on failure cri. ria of collector breakdown voltage and reverse current, and emitter breakdown voltage. See Note 1.
Transistor, Vycor gettered germanium, 2N559.	1.02	50% failure. See Note 1.

Notes:

1. Calculated from Arrhenius-type plots.

2. Burned in @ 125 deg. C, then powered during life testing @ 250 deg. C. Main failure mode was high leakage currents.

K_0 = reaction rate in the absence of applied stress

K = reaction rate in the presence of applied stress

k = Boltzmann's constant

T = absolute temperature

a, b, c,
d, and w = experimentally determined constants independent of time, temperature, and stress

S = a function of the applied stress

$n = c + (d/kT)$

The Inverse Power model has been applied to problems such as the fatigue testing of metals, the dielectric breakdown of capacitors, and the aging of multicomponent systems. It has the following general form: (Ref. 8)

$$L = 1/kV^n$$

where,

L = time to reach a specified endpoint

k,n = positive parameters characteristic of the material and test method

V = stress (e.g. current, voltage, temperature)

The 10-degree rule is an approximate relationship for describing the rate of a temperature-dependent reaction. It has been empirically derived and often fits the observed data well. The rule states that for each 10-degree (C or K) rise in temperature, the specific reaction rate doubles. The general form of the equation describing this relationship is as follows: (Ref. 8)

$$R = C2^{[(T_1 - T_0)/10]}$$

where,

R = the specific reaction rate

C = constant determined by experiment

T = temperature, degree C or K

A better match between the model and experimental data can often be achieved by modifying the 10-degree rule using a value for the constant, usually ranging from 5 degrees to 20 degrees C, which best fits the data.

The interpretation of the results from ALT is the subject of frequent controversy. According to S. P. Carfagno (Ref. 8), aging that can be accelerated in ways that yield verifiable correlation between real and simulated aging is an exception rather than the rule. Several environmental and operational stresses may cause degradation which is dependent upon the stress level, time, changes in stress level, and the sequence of such changes. Since it is very difficult to predict the stress history that a component will experience in service, the specification of ALT parameters to simulate the service life is also very difficult.

Models relating the causative factors to equipment degradation are essential to accelerate equipment aging. The models presented here, despite the considerable mathematical sophistication of some, are only rather simple approximations of the real-life problem and sufficient correlation with observed real-time aging to substantiate their validity for long periods of time is not available. While the models require experimental determination of key parameters, this has only been accomplished for very few components, and then for comparatively simple stress histories.

In conclusion, equipment aging on a rigorous scientific basis appears to be beyond the present state of technology. While it is inappropriate to use the results of presently available accelerated aging techniques to qualify the service life of an equipment, it is appropriate to use these results to assess qualitatively the vulnerability of equipment with respect to aging effects. For a more detailed discussion of the theory and practical application of ALT techniques, the reader should refer to References 8, 9, and 10.

5.2.4 Environmental Stress Screening

Analysis of dormant systems has consistently come to the conclusion that most failures that occur during dormancy are the result of latent defects that were not removed from the product during post assembly testing. Environmental Stress Screening (ESS) is a technique which has in recent years come to the forefront as a method to detect the presence of latent defects at any level of assembly from the component to the system level before the item is sent to the next level of assembly or to the ultimate user. ESS is finding growing use by defense electronic contractors as a means to precipitate failures due to latent defects as early as possible to reduce costs and to provide higher field reliability. ESS is particularly of interest for dormant systems because it is primarily designed to screen out the latent defects that have historically accounted for the majority of failures during dormant periods.

The process of ESS detects latent defects by subjecting test items to specific conditions of environmental stress, so that such defects can be degraded to a detectable level. Temperature cycling and random vibration appear to be the most effective tests, however, due to the varied nature of military electronics equipment and their associated design, development, and production program elements, a standard ESS approach is not feasible and a tailoring of the screening process to the unique elements of a given program is required. (Refs. 11 and 12) While a standard approach is not feasible, the Institute of Environmental Sciences has made the following conclusions based upon ESS program experience to date: (Ref. 12)

- The major objectives of a screening program are to reduce overall cost, improve productivity, and assure field reliability.
- Each ESS program is by nature hardware unique.
- The tailoring of screens should be considered a normal part of any ESS program.
- Stress screening parameters should be dynamic to permit their modification and/or elimination as the product matures.
- As a product matures, the quantity and nature of the defects precipitated by the screens depends on the effectiveness of the failure analysis and corrective action program instituted, and on the adaptation of the screens to current manufacturing processes and conditions.
- Stress screening levels should not exceed design limits.
- Temperature cycling precipitates 2/3 of all defects and random vibration precipitates the remaining 1/3.

- The combined environments of temperature cycling and vibration do not appear to be any more effective than environments applied sequentially and they are considerably more expensive than sequentially applied environments.

- Random vibration is more effective than either fixed frequency or swept sine vibration as an environmental screen.

- Module level screening is effective with or without power applied. The additional defects precipitated by the application of power do not appear to justify the added costs in most cases.

- Unit and system level screening is more effective if power is applied to the hardware.

It is beyond the scope of this report to fully describe all of the steps necessary to develop an effective ESS program. Over the past several years, various guidance documents have been published towards this purpose. An overview and comparison of the major documents is presented in tables 5.2.4-1 and 5.2.4-2. They should be consulted for further details. In addition, Reference 12 describes a set of three computer programs which can be used in selecting screens, setting screening parameters, and adjusting screens on the basis of observed results in order to find the optimum set of screens to achieve desired program objectives.

5.3 FIELD EVALUATION METHODS

This section covers two topics regarding the evaluation of fielded dormant systems. A model useful for assessing the readiness and maintainability of dormant systems using field maintenance data is presented in section 5.3.1. A discussion of the "certified round" concept for conducting periodic test and recertification of dormant systems is covered in section 5.3.2.

5.3.1 Readiness/Maintainability Assessments Using Field Data

Reference 14 describes a general model for assessing the readiness and maintainability of stockpiled dormant systems. The model utilizes field maintenance data available from most field data reporting systems and permits assessments over any time period for which data is available. By segregating the field maintenance data into active, logistic, and administrative time categories, the model can be used to demonstrate the effects that each time category has on stockpiled dormant system readiness and maintainability. While the model was specifically developed for stockpiled dormant systems, it is also applicable to actively used equipment.

Table 5.2.4-1 *Overview of Environmental Stress Screening Documents for Electronic Assemblies - Part 1 (Ref. 13)*

DOCUMENT	APPLICATION/DESCRIPTION	RANDOM VIBRATION			SEQUENCE
		AXIS/AXES	DURATION	SPECTRUM	
R&M 2000 ENVIRONMENTAL STRESS SCREENING(DEC. 1985), "GENERAL GUIDELINES AND MINIMUM REQUIREMENTS" (UPDATED 22 APR 1986)	- IMPLEMENT FOR ALL USAF ACQUISITIONS - APPLIES TO PIECE PARTS, SUBASSEMBLIES, AND EQUIPMENT	2 MINIMUM SERIALLY OR IN COMBINATION	10 MIN/AXIS (SERIALLY) OR 10 MINUTES (CONCURRENTLY)	.04 g^2/HZ FROM 20 TO 2000 HZ (INPUT); SHAPE NOT DEFINED	AT LEAST 5 TEMPERATURES MUST BE PERFORMED AFTER VIBRATION FOR EQUIPMENT, BOXES OR DRAWERS
DoD 4245.7-M (SEPTEMBER 1985), "TRANSITION FROM DEVELOPMENT TO PRODUCTION"	- BASED ON "TEMPLATES" TO DEFINE CRITICAL ENGINEERING PROCESSES AND CONTROL METHODS - ESS TO BE PERFORMED ON 100% OF EQUIPMENT - LAST TEMPERATURE CYCLE MUST BE FAILURE-FREE	3	10 MIN. TOTAL	6 GRMS FROM 100 TO 1000 HZ (INPUT); SHAPE NOT DEFINED	NO GUIDANCE PROVIDED
MIL-STD-781D "RELIABILITY TESTING FOR ENGINEERING DEVELOPMENT, QUALIFICATION, AND PRODUCTION", (TASK SECTION 400 RELEASE PENDING)	- USED IN CONJUNCTION WITH MIL-STD-2164 (EC) AND MIL-HDBK-781 (PARA. 4.4) - APPLIED TO 100% OF EQUIPMENT - FAILURE FREE PERIOD (LAST 2 CONSECUTIVE TEST CYCLES) REQUIRED	1-3	10 MIN (ONE AXIS) OR 5 MIN PER AXIS (MORE THAN ONE AXIS)	OVERALL SPECTRUM FROM 20 TO 2000 HZ, 0.4g^2/HZ FROM 80 TO 350 HZ (INPUT)	NO GUIDANCE PROVIDED
MIL-STD-2164 (EC) (5 APRIL 1985), "ENVIRONMENTAL STRESS SCREENING PROCESS FOR ELECTRONIC EQUIPMENT"	- RIGOROUSLY DEFINES ALL ENVIRONMENTAL CONDITIONS - APPLIED TO 100% OF EQUIPMENT - DEFECT-FREE PERIOD (40 HOURS OF TEMPERATURE CYCLING + 5 MIN. OF VIBRATION) REQUIRED - CONFLICTS WITH MIL-STD-781	1	5 MIN. PRIOR TO THERMAL CYCLING AND 5 CONSECUTIVE DEFECT-FREE MIN IN 15 MIN WINDOW AFTER DEFECT-FREE THERMAL CYCLING	OVERALL SPECTRUM FROM 20 TO 2000 HZ, .04g^2/HZ FROM 80 TO 350 HZ (INPUT)	PRE-DEFECT FREE VIBRATION AND TEMPERATURE CYCLING FOLLOWED BY DEFECT-FREE TEMPERATURE CYCLING AND VIBRATION
ESD PRODUCT ASSURANCE HANDBOOK/ESDR 800-5 (JUNE 1986)(METHOD 15)	- CONTRACTOR ESS STANDARD MAY BE USED UPON APPROVAL BY GOVERNMENT - LAST TWO TEMPERATURE CYCLES MUST BE FAILURE FREE	2 - 3 SERIALLY OR IN COMBINATION	10 MIN./AXIS	.045g^2/HZ (AVG.) FROM 20 TO 1000 HZ; SHAPE NOT DEFINED	VIBRATION RECOMMENDED BEFORE TEMPERATURE CYCLING

Table 5.2.4-1. Overview of Environmental Stress Screening Documents for Electronic Assemblies - Part 1 (Continued) (Ref. 12)

DOCUMENT	APPLICATION/DESCRIPTION	RANDOM VIBRATION			SEQUENCE
		AXIS/AXES	DURATION	SPECTRUM	
AMCR 702-25 "AMC ENVIRONMENTAL STRESS SCREENING PROGRAM" (TO BE RELEASED)	- ESS OPTIMIZATION TO BE PERFORMED DURING DEVELOPMENT PHASE - ESS TO BE USED WITH A FAILURE REPORTING ANALYSIS AND CORRECTIVE ACTION SYSTEM - LAST CYCLE MUST BE FAILURE FREE	3	10 MIN./AXIS	$.04g^2$/HZ (FREQ. RANGE AND SHAPE TO BE DEFINED)	NO GUIDANCE PROVIDED
NAVSEA NOTICE 3900 SER. 111 (8 FEB. 1984), "ELECTRONIC HARDWARE STRESS SCREENING"	- APPLIES TO ALL NAVSEA SYSCOM SHIPS, SYSTEMS, AND EQUIPMENT - AMOUNT OF ESS CAN BE REDUCED WHEN PROCESS YIELDS ARE HIGH - REFERENCES NAVMAT P-9492 - ALSO INCLUDES PARTS ESS BASELINE	2	10 MIN./AXIS	OVERALL SPECTRUM FROM 20 TO 2000 HZ, $.04g^2$/HZ FROM 80 TO 350 HZ (INPUT)	NO GUIDANCE PROVIDED
NAVMAT P-9492 (MAY 1979), "NAVY MANUFACTURING SCREENING PROGRAM"	- CONTAINS GUIDELINES, NOT POLICY - LAST TEMPERATURE CYCLE TO BE FAILURE FREE	1-3 (ORIENTATION WITH VIBRATION AXIS PERPENDICULAR TO PC BOARDS)	> - 10 MIN. (ONE AXIS) OR > - 5 MIN. (MORE THAN ONE AXIS)	OVERALL SPECTRUM FORM 20 TO 2000 HZ $.04g^2$/HZ FROM 80 TO 350 HZ (INPUT)	NO GUIDANCE PROVIDED
IES "ENVIRONMENTAL STRESS SCREENING GUIDELINES FOR ASSEMBLIES" (SEPTEMBER 1984)	- RECOMMENDATIONS NOT INTENDED TO BE EXTRACTED AND LEVIED AS FIRM REQUIREMENTS - RECOMMENDATIONS TO BE USED AS POINT OF DEPARTURE	1-3 (3 NOMINAL)	10 MIN/AXIS NOMINAL	3 TO 10 GRMS FROM 100 TO 1000 HZ, 6 GRMS NOMINAL (INPUT)	- ESS EFFECTIVENESS APPEARS INDEPENDENT OF SEQUENCE - SECOND SERIES OF TEMPERATURE CYCLES AFTER VIBRATION WILL PRECIPITATE ADDITIONAL FAILURES STIMULATED BY VIBRATION

Table 5.2.4-2. Overview of Environmental Stress Screening Documents for Electronic Assemblies - Part 2 (Ref. 13)

DOCUMENT	TEMPERATURE CYCLING			POWER ON/OFF	
	CHANGE RATE	RANGE	NO. OF CYCLES	TEMPERATURE CYCLING	VIBRATION
R&M 2000 ENVIRONMENTAL STRESS SCREENING(DEC. 1985),"GENERAL GUIDELINES AND MINIMUM REQUIREMENTS" (UPDATED 22 APR 1986)	30°C/MIN FOR SUBASSEMBLIES(SRUs) 5°C/MIN FOR EQUIPMENT, BOXES, OR DRAWERS (LRUs) (NO DWELL AFTER STABILIZATION)	-54°C TO +85°C FOR SUBASSEMBLIES -54°C TO +71°C FOR EQUIP., MENT, BOXES, OR DRAWERS (RAPID TRANSFERS BETWEEN HOT AND COLD CHAMBERS ACCEPTABLE)	> - 25 FOR SUBASSEMBLIES > - 10 FOR EQUIPMENT, BOXES, OR DRAWERS (MINIMUM OF 5 MUST BE COMPLETED AFTER VIBRATION)	EQUIPMENT ON AT MAXIMUM POWER LOADING WITH INSTANTANEOUS GO/NO-GO PERFORMANCE MONITORING POWER OFF DURING TEMPERATURE DROP POWER TURNED ON/OFF AT LEAST 3 TIMES AT TEMPERATURE EXTREMES	
DoD 4245.7-M (SEPTEMBER 1985),"TRANSITION FROM DEVELOPMENT TO PRODUCTION"	10°C/MIN FOR ALL ASSEMBLY LEVELS	-40°C TO +60°C FOR ALL ASSEMBLY LEVELS	15 FOR ALL ASSEMBLY LEVELS (LAST CYCLE MUST BE FAILURE FREE)	POWER OFF DURING TEMPERATURE DROP	POWER ON
MIL-STD 781D "RELIABILITY TESTING FOR ENGINEERING DEVELOPMENT, QUALIFICATION, AND PRODUCTION",(TASK SECTION 400 RELEASE PENDING)	> - 5°C/MIN FOR ALL ASSEMBLY LEVELS BUT LESS THAN THERMAL SHOCK (CHANGE RATE OF INTERNAL PARTS SHOULD BE BETWEEN -17°C AND 4.4°C/MIN.)	SELECTED RANGE BETWEEN -54°C AND +55°C FOR ALL ASSEMBLY LEVELS	1 FOR SIMPLE EQUIPMENT (100 ELECTRONIC PARTS) 3 FOR MODERATELY COMPLEX (500 PARTS) 6 FOR COMPLEX (2000 PARTS) 10 FOR VERY COMPLEX (4000 PARTS) (LAST 2 MUST BE FAILURE FREE)	EQUIPMENT TO BE ON AND CYCLED THRU OPERATING MODES (EXCEPT DURING COOL DOWN), WITH PERFORMANCE MONITORED CONTINUOUSLY, IF FEASIBLE	EQUIPMENT TO BE ON AND CYCLED THRU OPERATING MODES
MIL-STD 2164 (EC) (5 APRIL 1985),"ENVIRONMENTAL STRESS SCREENING PROCESS FOR ELECTRONIC EQUIPMENT"	5°C/MIN FOR ALL ASSEMBLY LEVELS	BASED UPON EQUIPMENT DESIGN CATEGORY (I.E. MIL-E-5400, CLASS 1)	40 TO 80 HOURS OF 3.5 HOUR CYCLES. LAST 40 HOURS MUST BE DEFECT FREE	FUNCTIONAL MONITORING TO FULLEST EXTENT PRACTICAL	

Table 5.2.4.2. Overview of Environmental Stress Screening Documents for Electronic Assemblies - Part 2 (Continued) (Ref 13)

DOCUMENT	TEMPERATURE CYCLING			POWER ON/OFF	
	CHANGE RATE	RANGE	NO. OF CYCLES	TEMPERATURE CYCLING	VIBRATION
ESD PRODUCT ASSURANCE HANDBOOK/ESDR 800-5 (JUNE 1986) (METHOD 15)	30°C/MIN FOR PC BOARDS 5°C/MIN FOR EQUIPMENT, BOXES, OR DRAWERS, SYSTEMS OF PRIME ITEMS	-54°C TO $+85^{\circ}$C FOR SRUs -54°C TO $+71^{\circ}$C FOR EQUIP-MENT BOXES, OR DRAWERS, SYSTEMS OR PRIME ITEMS	25 FOR PC BOARDS 10 FOR EQUIP MENT, BOXES, OR DRAWERS 5 FOR SYSTEM OR PRIME ITEM	EQUIPMENT ON AT MAXIMUM POWER LOADING WITH INSTANTANEOUS GO/NO-GO PERFORMANCE MONITORING POWER OFF DURING TEMPERATURE DROP 3 ON/OFF CYCLES MINIMUM DURING EACH TEMP. CYCLE	
AMCR 702-25 "AMC ENVIRONMENTAL STRESS SCREENING PROGRAM" (TO BE RELEASED)	15°C/MIN FOR ASSEMBLIES 10°C/MIN FOR UNITS AND SYSTEMS (NO DWELL AFTER STABIL-IZATION)	-50°C TO $+75^{\circ}$C FOR ASSEM -40°C TO $+70^{\circ}$C FOR UNITS -40°C TO $+60^{\circ}$C FOR SYSTEMS (RAPID TRAN-FERS BETWEEN HOT AND COLD CHAMBERS ACCEPTABLE)	20 FOR ASSEM-BLIES 12 FOR UNITS AND SYSTEMS (LAST CYCLE MUST BE FAIL-URE FREE)	POWER OFF AT ASSEMBLY LEVEL POWER ON AND PERFORMANCE MONITORED AT UNIT AND SYSTEM LEVELS	
NAVSEA NOTICE 3900 SER. 111 (5 FEB. 1981) "ELECTRONIC HARDWARE STRESS SCREENING"	NO CHAMBER RATE GIVEN, $> +5^{\circ}$C/MIN MEASURED ON ELECTRONIC COMPONENTS	-40°C TO $+95^{\circ}$C FOR ALL ASSEMBLY LEVELS	10 TO 20 DEPENDING ON THE ASSEMBLY LEVEL (LAST CYCLE MUST BE FAIL-URE FREE)	POWER ON EXCEPT FOR MODULES ON MATURE PRODUC-TION HARDWARE	NO GUIDANCE PROVIDED
NAVMAT P 9492 (MAY 1979), "NAVY MANUFAC-TURING SCREENING PROGRAM"	NO CHAMBER RATE GIVEN; CHANGE RATE OF INTERNAL PARTS SHOULD BE BETWEEN 0.5° AND 22°C/MIN.	-54°C TO $+55^{\circ}$C (MINIMUM DELTA T OF 89°C RECOMMEND-ED)	1 FOR SIMPLE ELECTRONIC EQUIPMENT (100 ELEC-TRONIC PARTS) 3 FOR MODER-ATELY COMPLEX (500 PARTS)	EQUIPMENT ON EXCEPT DURING TEMPERATURE DROP CONTINUOUS PERFORMANCE MONITORING DESIREABLE BUT PERIODIC CHECKS ACCEPTABLE	EQUIPMENT MAY OR MAY NOT BE ON

Table 5.2.4-2. Overview of Environmental Stress Screening Documents for Electronic Assemblies - Part 2 (Continued) (Ref. 13)

DOCUMENT	TEMPERATURE CYCLING			POWER ON/OFF	
	CHANGE RATE	RANGE	NO. OF CYCLES	TEMPERATURE CYCLING	VIBRATION
NAVMAT P 9492 (MAY 1979), "NAVY MANUFACTURING SCREENING PROGRAM" (CONTINUED)			6 FOR COMPLEX (2000 PARTS) 10 FOR VERY COMPLEX (4000 PARTS) (LAST CYCLE MUST BE FAILURE FREE)		
IES "ENVIRONMENTAL STRESS SCREENING GUIDELINES FOR ASSEMBLIES" (SEPTEMBER 1984)	10°C/MIN (NOMINAL) FOR MODULES ?°C/MIN (NOMINAL) FOR UNITS AND SYSTEMS	-50°C TO +75°C (NOMINAL FOR MODULES) -40°C TO +70°C (NOMINAL) FOR UNITS -40°C TO +60°C (NOMINAL) FOR SYSTEMS	20 FOR MODULES 12 FOR UNITS AND SYSTEMS	POWER OFF AT MODULE LEVEL POWER ON AT UNIT/SYSTEM LEVEL	EITHER OPERATING OR NON OPERATING AT MODULE LEVEL OPERATING AT UNIT/SYSTEM LEVEL

The following assumptions provide the basis for the model:

1. An item is assumed ready if it is not undergoing a maintenance action. An item is assumed not ready while it is undergoing a maintenance action.

2. Items undergoing maintenance actions that do not preclude immediate use are considered ready while such maintenance is being performed (e.g. simple spot painting of a container).

3. There is no distinction between an item in storage (non-operating) and an item in use when assessing an operating/nonoperating mixture of items.

4. An item is considered ready if maintenance is completed within an allowed turnaround time T.

5. Readiness is based upon total calendar time.

6. No new maintenance actions are started during the allowed turnaround time. Once an item becomes ready during this time, it is considered ready for the duration.

7. In situations where a failure has occurred, an item is assumed ready up to the detection of the failed condition.

Readiness and maintainability as used in the context of the model are defined as follows:

<u>Readiness (U(T))</u>

U(T) = the percentage of items that can be placed in use within an allowable turnaround time (T) after use is called for at a random (unknown) point in time.

<u>Maintainability (M(T))</u>

M(T) = the percentage of items not immediately ready for use that can be made ready for use within an allowable turnaround time (T) after use is called for at a random (unknown) point in time.

The basic relationship between readiness and maintainability is then defined by the following equation:

$$U(T) = U(0) + M(T)[1 - U(0)]$$

where,

$U(T)$ = stockpile readiness for an allowable turnaround time T.

$U(0)$ = immediate stockpile readiness (T=0).

$[1 - U(0)]$ = immediate stockpile unreadiness (T=0).

$M(T)$ = stockpile maintainability for allowable turnaround time T.

This equation illustrates that readiness for an allowable turnaround time is composed of two parts: (1) the fraction of the stockpile that is immediately ready ($U(0)$), and (2) the fraction of the stockpile that is restored within T ($M(T)[1 - U(0)]$).

The derivation of the constituent parts then proceeds as follows:

$$[1 - U(0)] = (\Sigma t_M)/(N \times t_{CAL})$$

where,

Σt_M = the total maintenance time for all maintenance actions occurring during the period for which the assessment is being performed.

N = the number of items in the stockpile during the period for which the assessment is being performed.

t_{CAL} = the calendar time of the period for which the assessment is being performed.

and,

$$U(0) = 1 - [1 - U(0)]$$

Maintainability is described by the following equation:

$$M(T) = [\Sigma t_M(t_M \leq T) + N(t_M > T) \times T]/(\Sigma t_M)$$

where,

$\Sigma t_M(t_M \leq T)$ = the sum of the maintenance time for all maintenance actions during the period that could be completed within T.

$N(t_M > T)$ = the total number of maintenance actions during the period that took greater than T time to complete.

T = the allowable turnaround time.

Σt_M = the total maintenance time for all maintenance actions occurring during the period.

These two equations are subject to two restrictions. First, the number of items in the stockpile (N) must be constant over the assessment period and second, maintenance actions must not overlap the boundaries of an assessment period. (i.e. All maintenance actions that occur during the period are assumed to have started and ended during the period.) To remove these restrictions, the following equations should be applied:

$$[1 - U(0)] = (\Sigma t_M - \Sigma t_M^- - \Sigma t_M^+)/(N_{AVG} \times t_{CAL})$$

$$= (\Sigma t_{MC})/(N_{AVG} \times t_{CAL})$$

and,

$$M(T) = [\Sigma t_{MC}(t_M \leq T) + \Sigma(T - t_M^+)(\text{for } t_M > T \geq t_M^+ \;\&$$

$$(T - t_M^+) \leq t_{MC}) + \Sigma t_{MC}(\text{for } t_M > T > t_M^+ \;\&$$

$$(T - t_M^+) > t_{MC})]/(\Sigma t_{MC})$$

where,

Σt_M^+ = the total amount of time expended <u>after</u> the end of the assessment period for all maintenance actions occurring during the assessment period.

Σt_M^- = the total amount of time expended <u>before</u> the start of the assessment period for all maintenance actions occurring during the assessment period.

Σt_{MC} = the total amount of time expended <u>during</u> the assessment period for all maintenance actions occurring during the assessment period.

$= \Sigma t_M - \Sigma t_M^- - t_M^+$

N_{AVG} = the weighted-average number of items in the stockpile over the assessment period.

Reference 14 also contains derivations of these equations that can be used during development when field data is not available. The conversion terms are as follows:

$$\Sigma t_M = MDT \times (N_{AVG} \times t_{CAL})/(MTBMA + MDT)$$

$$\Sigma t_M(t_M \le T) = [(N_{AVG} \times t_{CAL})/(MTBMA + MDT)] \times {}_0\int^T (m(t) \times t)dt$$

$$N(t_M > T) = [(N_{AVG} \times t_{CAL})/(MTBMA + MDT)] \times [1 - {}_0\int^T m(t)dt$$

where,

MTBMA = mean time between maintenance actions

MDT = mean down time.

m(t) = the maintenance probability density function (i.e. the probability that a maintenance action takes t time to complete).

After substituting these conversion terms, the equations for readiness and maintainability become:

$$M(T) = [{}_0\int^T (m(t) \times t)dt + (1 - {}_0\int^T m(t)dt) \times T]/MDT$$

$$[1 - U(0)] = MDT/(MTBMA + MDT)$$

$$U(0) = MTBMA/(MTBMA + MDT)$$

5.3.2 Periodic Test and Recertification

As discussed in section 4.3, the objective of periodic testing and recertification of dormant equipment is to ensure the reliability of the equipment through the detection and repair of non-operating failures before the equipment is called upon to perform a mission. It is not applicable to all dormant equipment and should only be employed where it is necessary to ensure that equipment reliability does not fall below the minimum acceptable reliability over the equipment service life. (See section 4.3 for further details concerning test/no-test tradeoffs.) When it is necessary, however, it is very important that the test and recertification operations be carefully controlled in order to avoid the introduction of contaminants that can cause long-term non-operating reliability problems, and to avoid failures induced by the monitoring and repair operations, some of which may go undetected.

To minimize the undesirable effects of test and recertification operations, an approach called the "certified round concept" has been instituted on dormant systems (e.g. IHAWK) with very good results. (Ref. 15) An essential element of this approach is the employment of deployable test and repair stations housed in a controlled environment which duplicates the conditions under which the equipment was originally built and tested. On the IHAWK program they are called Theater Readiness Monitoring Facilities (TRMF). They permit the testing and repair of fielded equipment in a known, controlled environment so that maintenance induced failures and the introduction of contaminants are minimized. In addition, since the test conditions duplicate those during which the equipment was initially tested at the manufacturing facility, the test results from the TRMF can be directly compared with baseline tests that were conducted during manufacturing.

The "certified round concept" requires the initial certification of each lot of equipment produced. The initial certification is performed using equipment of the same type that is employed in the TRMF. All data from this testing is retained in a central data bank for future reference.

After initial certification and lot acceptance, the equipment is deployed. At prescribed intervals after deployment (see section 4.3 for methods of determining optimum test intervals), a random sample of each lot of equipment is selected for recertification testing at the TRMF. During recertification, the selected equipment are subjected to the identical tests that were employed during initial certification testing. Should an equipment fail, it is repaired using repair test sets included in the TRMF. All data gathered during recertification is then stored in a data bank and later compared to the initial certification data to determine trends in equipment reliability degradation during its fielded life due to operation, transportation, handling, and storage.

5.4 SPECIAL EVALUATION METHODS

In addition to the evaluation methods described in the previous sections, systems that spend most of their service life cycles in non-operating states are often subjected to special evaluations to determine the impact of long-term non-operating periods. This section describes three special evaluation methods. Section 5.4.1 covers stockpile laboratory testing programs. Section 5.4.2 covers stockpile flight test programs. Finally, section 5.4.3 covers special real-time component aging programs.

5.4.1 Stockpile Laboratory Testing Programs

Stockpile laboratory test programs are detailed test, analysis, and reporting programs that are designed to compare a dormant system to established standards for projecting shelf and service life throughout its life cycle. Under these programs, samples of fielded dormant systems are periodically removed from storage and examined for degredation from original specifications or the results of prior tests. The examinations typically include disassembly, inspection, ATP testing of all critical components, the actuation of one-shot devices, and root-cause analysis of all failures.

The primary objective of these tests and analyses is to discover evidence of deterioration during storage and to assess the readiness and reliability of the stockpile. If evidence of deterioration is detected, the test results are used to develop corrective action measures.

Because of the limited number of samples that are evaluated during stockpile laboratory test programs, the assessment of reliability by conventional attribute failure classification methods is generally not feasible. However, in Reference 17, H. Hecht describes a reliability estimation method which permits the attainment of a given confidence level with a smaller sample size or the attainment of a higher confidence level with a given sample size utilizing the numerical measurements obtained from laboratory test programs. Called the Design Margin Approach, it is best employed for equipment where the principal failure modes are well identified and where these can be attributed to quantitative levels of a few specific measurements.

For the case of a minimum acceptable parameter value, the Design Margin Approach computes reliability as follows:

x_i = the measurement taken for the iih system in the test group for the test parameter to be evaluated.

L = the lower acceptance limit specified for the test parameter in question.

D = the design margin.

m = the mean of the x_i values for the given test parameter of the given group of systems.

s = the standard deviation of the x_i values for the given test parameter for the given group of systems.

d = the non-dimensional design margin.

n = the sample size - i.e. number of systems under test.

The design margin is defined to be:

$$D = m - L$$

The non-dimensional design margin is defined to be:

$$d = D/s$$

If it is assumed that the x_i values are normally distributed, then the probability that x_i will fall more than D below the mean is equivalent to the probability that the standardized normal variate will fall above the number representing the non-dimensional design margin. The probability (P(d)) that the standardized normal variate will fall above d can be found in any table of the cumulative distribution. Once the P(d) value is known, the value of the reliability (R) of the system can be calculated from:

$$R = 1 - P(d)$$

The following sample calculation is included to clarify this calculation. Suppose a test parameter of a group of systems has a D value of 3.6 units and a d value of 1.68. Then the P(d) value can be found in any table of the cumulative normal probability distribution as P(d = 1.68) = 0.046. Then the reliability of the system is calculated to be 0.954.

For the case of a maximum acceptable parameter value, the design margin would be calculated using the upper limit value (U) in place of the lower limit value (L). The remaining calculations would then proceed in the same manner. For the case of a two sided limit on a parameter value, both the upper and lower design margins would be calculated as described. The reliability would then be calculated as follows:

$$R = 1 - P(d_L) - P(d_U)$$

where $P(d_L)$ and $P(d_U)$ are the standardized normal variate probabilities for the lower and upper non-dimensional design margin values.

The design margin approach produces different R values than the conventional approach to calculating R. In particular, in the design margin approach, the computed reliability does not necessarily change if an additional system or measurement is added to the data. Additional information concerning the estimation of reliability confidence intervals and the estimation of differences using the Design Margin Approach is presented in Reference 17.

5.4.2 Stockpile Flight Test Programs

Stockpile flight test programs are primarily applied to one-shot systems such as missiles or munitions. Under these programs, samples of fielded systems are functioned (e.g. fired, launched, detonated, etc.) to determine the degree to which they actually perform in accordance with specified requirements for reliability, accuracy, range, etc. This information is then used to assess the degree to which the remaining items in the stockpile meet the specified performance requirements and to determine if any corrective action is necessary to improve performance to desired levels.

For the most part, the complexity of the flight test program will be a function of the complexity of the item being tested. In the case of a very simple item, such as a projectile fuze, the test program may simply consist of setting the fuze, firing it, and then observing if the test projectile detonated as required. For a very complex item, such as a ballistic missile, the test program may entail the monitoring of a vast array of telemetry data during the flight test supplied by special telemetry equipment installed prior to launch. Such information is vital to determine if the missile performed properly throughout the test and to isolate the cause in the event of a failure.

The cost of the test item will also impact the number of items that can be tested. For relatively inexpensive items, the sample test plans specified in MIL-STD-105 (Ref. 18) can be used to determine the sample size and accept/reject criteria for a particular level of confidence. For expensive items, Reference 19 provides a Bayesian based sampling method for reducing the number of samples necessary to achieve a desired confidence level.

5.4.3 Real-Time Component Aging Programs

Stockpile laboratory and flight test programs can be expensive to perform. In addition to the direct costs associated with performing the tests, the logistic costs associated with the movement of entire systems or parts of systems can be substantial. If the testing results in the destruction of the item being evaluated, its cost must also be considered.

Real-time component aging has been employed as a means of reducing the costs associated with the evaluation of the long-term dormant storage deterioration of fielded systems. The objective of such programs is to perform continual automated testing of critical devices of a system, rather than the systems themselves, at a central location. In this way the test procedures can be greatly simplified and the test results can be potentially applied to a variety of different systems. (Ref. 16)

The test devices are chosen at random from production lots and are mounted in special test fixtures. The test fixtures are then mounted in an automated test system consisting of computer controlled measuring instruments. The computer is programmed to periodically test each component at prescribed intervals and store all measured values for later analysis for trends.

When conducting real-time aging programs, it must be realized that the deterioration rates being measured may be quite small while the random variations can be quite large. Many random perturbations of the data can exist. Besides the effects of temperature and humidity, there are the effects of ac line voltage variations, amplifier drift, and environmental electrical equipment transients. One method of coping with this problem is to examine the mean behavior of all devices within a device type, rather than particular devices individually. Such averaging will tend to filter random perturbations. (Ref. 16)

The massive amounts of data that must be processed must also be considered. The data analysis program must be able to manipulate the data file created by the data measuring system and must be able to handle the amount of data collected over the projected program time span.

In order to determine if the devices exhibit a wearout condition due to the repetitive testing, it is recommended that the test devices be divided into three groups, each having a different testing rate (such as differing by a factor of 2). To determine if a correlation exists between testing rate and device deterioration, the percentage of measurements of a group beyond the mean as a function of time should be examined. For example, if test results indicate that a particular test parameter has increased with time, then, if this is a consequence of testing and not storage, the group that is tested most often would increase most rapidly. Since the mean computations make no group distinctions, the percentage of measurements above the mean for the most frequently tested group should increase with time. Conversely, the percentage of measurements above the mean for the least frequently tested group should decrease with time. The remaining group should lie somewhere between these two groups. The opposite situation would occur if the parameter decreased with time and it exhibited a wearout condition due to the repetitive testing.

The primary disadvantage of this method is that the environment experienced by the test components is, in most cases, not the same as the environment experienced by the fielded systems which are being evaluated. Even if environmental parameters such as temperature and humidity closely approximate the conditions in the field, significant differences in other environmental factors may yield results with low correlation to actual field experience. For example, a corrosive environment may result in the field due to the outgassing of certain components in the fielded system. The effects of this corrosive environment would not be reflected in the component aging program unless it was known beforehand and was duplicated in the aging program. Since this is unlikely, it is recommended that real-time component aging not be relied upon as the sole method for evaluating the effects of long-term storage on fielded systems.

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6.0 PRODUCT PERFORMANCE AGREEMENTS

6.1 PRODUCT PERFORMANCE AGREEMENT OBJECTIVES

Product performance agreements (PPAs) are any form of warranty guarantee, or incentive used as a motivational strategy to improve product performance and support (Reference 1). They are required to be considered for weapon system production contracts by title 10 section 2403 of the United States Code on all weapon systems purchased after 1 January 1985 costing more than $100K per deliverable end item, or more than $10M for the total procurement and must guarantee:

- conformance to essential performance requirements,
- conformance to design and manufacturing requirements,
- freedom from defects in materials and workmanship.

This requirement applies to weapon systems in mature full scale production. The essential performance requirements coverage is excluded from the first 10% of the total production quantity, or the first year's production quantity, whichever is less. In the event that it is determined that the PPA requirement is not in the interests of national defense or is not cost effective, the Secretary of Defense may waive the PPA requirement with proper notification to the House and Senate committees on Armed Services and Appropriations.

The objective of a PPA is to enforce the performance and (when required) the reliability and maintainability (R&M) specifications in order to deliver an effective and available weapon system to the Combat Commander. It seeks to accomplish this by providing the system manufacturer with a suitable incentive, positive or negative, to assume increased responsibility for post delivery performance.

An optional objective of some PPAs is to create a consistent pattern of R&M growth during development and deployment. The target is improved availability during system/item deployment at considerable savings in Life Cycle Cost (LCC). The trend of Operation & Maintenance (O&M) costs is an ever increasing share of total system cost. Per unit cost of a weapon system is not the sole criteria of affordability. Total LCC, of which O&M is over 50%, determine affordability. A low reliability and/or difficult to maintain, but moderately priced, item may not be affordable when the O&M costs are considered over the expected system life. (Reference 2.)

System R&M is a key concern because of its impact on mission capability. The price of modern weapon systems precludes the excessive O&M budget required to insure desired mission capability with less than desired system/item R&M. The maintenance overtime, system cross cannibalization, increased purchases of the materiel to effect repairs, and the increased transportation and administrative costs are reflected in the O&M budge. (Reference 2.)

Lacking the protection of a PPA, the Government was forced to absorb reliability shortfalls which reduced mission capability, and/or increased support costs. A PPA places greater responsibility for system field performance on the manufacturer. (Reference 2.)

It is difficult to conclusively prove that reliability measures observed on a program employing a PPA are the result of the PPA or whether the benefits obtained by the Government through the PPA exceed the cost of the PPA. One study (Reference 3) concluded that the search of warranty experience failed to reveal any overwhelming evidence to support the "success of warranties". It further concluded that while some benefits have occured in the contracts containing warranties, the separation of the benefits attributable to warranties vis-a-vis benefits attributable to other factors is unclear. Another study (Reference 4) investigating the effectiveness of Reliability Improvement Warranties (RIWs) concluded that the RIW was moderately effective for five of eight programs examined. The benefits realized included the temporary transfer of the risk associated with equipment field reliability to the production contractor(s), deferred Government investment of resources to maintain the fielded equipment, and improved reliability and maintainability over that which the Government could reasonably have expected to achieve without a warranty.

The effectiveness of PPAs applied to dormant equipment is even less clear. Reference 3, investigating the use of warranties in the acquisition of conventional munitions, concluded that, because of the unique features of munitions (one-shot, no maintenance, long dormant periods, no download provision, all up round concept, etc.), warranties do not provide incentives to contractors for improved product performance or reduced costs. It found that 3 of the 10 major warranty application criteria and 7 of the 14 secondary warranty application criteria could not be met. While reference 3 does not advocate the use of warranties as a general practice, it does conclude that the original objective of the product performance agreement to obtain what was contracted for at the least life cycle cost is still valid.

Product performance agreements are a relatively new phenomenon and innovative work is being put into these agreements. To be effective, they should be simple, focused on the primary objectives to be obtained, enforceable, affordable in relation to potential benefits, and should not cause disruption to existing military systems and procedures. (Reference 1) A correctly structured PPA must be tailored to the type of procurement, the characteristics of the equipment and mission, and the anticipated support environment. In many cases, a PPA may not be applicable or may even be a risky alternative. (Reference 3.)

The following sections present an approach for selecting, analyzing, structuring, and managing effective product performance agreements in general with specific guidance where appropriate for applying them to dormant equipment.

6.2 PRODUCT PERFORMANCE AGREEMENT SELECTION, ANALYSIS, AND STRUCTURE

Creating a Product Performance Agreement (PPA) that is suited to program requirements and objectives can be divided into five steps.

1. Establishment of a PPA working group.

2. Collection of program characteristics, objective, and equipment information.

3. Identification of alternative PPAs which best suit the program parameters.

4. Performance of in-depth cost, benefit, and risk analyses of the alternatives.

5. Development of program unique contract provisions, evaluation methods, and management techniques for the selected alternative(s).

These steps are described in the following paragraphs. Additional information concerning these steps can also be found in Reference 2, the Air Force Product Performance Agreement Guide, and Reference 5, the Air Force Product Performance Agreement Decision Support Handbook.

6.2.1 Establishment of PPA Working Group

The first step in developing a PPA approach to the acquisition of a system is the establishment of a working group to examine approaches and develop a PPA implementation strategy. This working group should be established as early as possible in the acquisition life cycle.

PPA concepts must be developed early in the program, along with the program planning, if they are to be consistent with the overall program acquisition strategy.

Selecting and tailoring an effective PPA requires a multidisciplinary approach with participation of the using commands, the acquisition and supporting commands, and subsequently the contractor. The complexity and potential impact of PPAs on logistics, cost, design trade-offs, etc., requires a team approach from the outset. Government participants are generally the same as those needed in developing the acquisition strategy and should include representatives from the following functional elements: (References 1 & 8.)

- Program Management
- Engineering (including quality assurance)
- Logistics
- Budget and program control
- Cost, pricing, and systems analysis
- Procurement
- Counsel
- Users

The using and supporting commands can offer valuable advice about the PPA approach to be considered. They are perhaps the most important members since they are the ones who will have to live with the system. (Reference 6.)

The contractor should be included in the working group as early as possible in the acquisition life cycle. This is very important as it was concluded in a study of the impact of warranties and guarantees on electronic system design and development programs (Reference 7) that delaying contractor invovlement in the development of the detailed terms and conditions of the PPA until negotiation of the production contract was found to inhibit important design trade-offs during the engineering development program. The contractor working group should include representatives from the same functional elements as the Government working group with the exception of the ultimate Users.

One method of accomplishing close contractor involvement is to place sample PPA provisions in a demonstration and validation RFP to put the contractor on notice that a PPA will probably be required on the production contract (Reference 1). The results from the demonstration and validation should then be used to tailor PPA requirements. Then when contractors are required to propose upon government developed clauses at the time of full-scale development (FSD), or later, they should also be allowed to propose alternatives to be evaluated by the government.

6.2.2 Data Collection

The next step in the development of a PPA implementation strategy is the collection of data concerning program characteristics, program objectives, and equipment description and characteristics. This data is necessary to select alternative PPAs, identify and evaluate potential PPA implementation problems and concerns, and analyze relevant PPAs.

Table 6.2.2-1, developed from Reference 5, can be used as an aid in collecting program characteristic data. It identifies the pertinent program characteristics and the data required to support the selection of PPAs.

In addition to the program characteristics data, information must be collected on the major objectives of the program, the details of the objectives in terms of the program and the specific equipment, and what their priorities are: (Reference 5.)

- Reducing or imposing a ceiling on costs:
  - operations and support costs
  - life-cycle cost
  - particular maintenance cost
  - parts cost, sparing cost, etc.

- Giving incentive to contractors to improve specific aspects of existing systems:
  - operating characteristics
  - maintainability
  - reliability
  - performance in operational environment
  - performance in storage (non-operating) environment

- Giving incentive to contractors to meet or exceed system performance specifications:
  - reliability (operating, non-operating)
  - reliability growth
  - mission completion
  - mission dependability
  - captive carry
  - specific performance task (e.g., satellite location change)
  - lifetime of a consumable component (e.g., brakes)

- Giving incentive to contractors to meet or exceed system maintenance specifications

- Basic materials, workmanship, correction of deficiencies coverage

Table 6.2.2-1. Program Characteristic Data for PPA Selection

Program Characteristic	Data Required
1. Multiservice Program	• Is the program multiservice? • Are there differences in objectives, operational environments, and/or physical characteristics of the system between the services (may necessitate different PPAs for each service).
2. Program Status	• Present status of the program (source selection, production , FSED, etc.) • The phase at which the PPA will be applied.
3. Sole Source Acquisition	• Is the acquisition sole source? • Contractual arrangement with multiple suppliers (i.e., leader/ follower, prime with subcontractors, etc.).
4. Budgetary Issues	• Budget Restrictions • Funding Sources
5. Currently Used PPAs	• Are there existing PPAs on the program? • What do they cover and for what period of time?
6. Previously Used PPAs	• Types of PPAs used on the program in the past. • Experience and results of those PPAs.
7. Program Schedule	• The program schedule including all phases of development, testing, production, and operation.

Table 6.2.2-1. Program Characteristic Data for PPA Selection (Continued)

Program Characteristic	Data Required
8. Interim Contractor Support	• Length of time and level of support.
9. Program Test Plans	• What do the test plans include (e.g., reliability, maintainability, performance, etc.)? • When will the tests be done? • The number of units tested and for how long. • The test environment. • Is there time and opportunity available after the tests to modify the equipment design?
10 Number of Years for for the PPA	• The number of years of program coverage by a PPA.

- Reducing risk to the government of acquiring substandard items
- Ensuring that the maintenance concept is feasible and realistic:
  - BIT requirements
  - MTTR parameters
  - Support equipment requirements
  - Turnaround time requirements
- Giving incentive to achieve or exceed availability/readiness requirements.

It must also be determined whether the objectives are relevant to:

- The system of unit as a whole
- Specific Line Replaceable Units (LRUs) only
- Specific Ship Replaceable Units (SRUs) only.

Finally, information concerning the equipment functional, operational, and physical characteristics must be collected. The type of information that must be obtained is identified in Table 6.2.2-2. This table was developed from information provided in Reference 5.

6.2.3 Alternative PPA Selection

The data collected in the previous step is used to determine preliminary PPA options for the relevant program using a PPA Selection Matrix (PSM) such as shown in figure 6.2.3-1. This matrix is used to match program objectives and characteristics with suitable PPAs, and to generate a preliminary list of suitable PPA options. It is divided into two parts with program agreement objectives as the rows of Part I, item characteristics as the rows of Part II, and PPA types as the column headings. An expanded PSM containing other PPAs is maintained in the PPA Decision Support System (DSS) at the Air Force Product Performance Agreement Center, Wright-Patterson AFB, Ohio. (Reference 5.)

The four symbols used in the matrix and their meanings are:

"=" Include this PPA in the list of potential PPAs.

"≠" Exclude this PPA from the list of potential PPAs.

"+" Indicates PPA is potentially relevant.

"-" Indicates PPA has possible negative impact to stated program objective or characteristic.

Table 6.2.2-2. Equipment Description and Characteristic Data for PPA Selection

Program Characteristic	Data Required
1. Equipment Name	• Relevant system, subsystem, or component name.
2. Parts Breakdown	• Equipment parts breakdown into LRU's and SRU's.
3. Equipment Function	• The intended function of the equipment.
4. Maturity	• If it is existing equipment, how has it previously performed, what were performance problems. (This will help determine what should be incentivized.) • If it is modified equipment, what are the modifications, how much do they contribute to the performance of the equipment, and what are the performance problems of the original equipment and are they addressed by the modifications. (This will help determine if the modifications affect performance, whether they alone should be warranted, and whether the modified system is expected to perform as the original system did.) • If it is new equipment, does it include advanced technology or mature technology. (The former is high risk in terms of expected performance, the latter is medium to low risk depending on the extent of the maturity and experience with the technology).
5. Government Furnished Equipment	• Identification of GFE, non-GFE and modifield GFE components. (The contractor cannot be responsible for performance/ design limitations of GFE.)
6. Production Quantity	• The number of units to be produced.
7. Life	• The lifetime of a unit.

Table 6.2.2-2. Equipment Description and Characteristic Data for PPA Selection (Continued)

Program Characteristic	Data Required
8. Average Operating Hours	• The average operating hours of a unit (per week, per month, etc.)
9. Life Cycle Environment	• Operation, storage, captive carry, etc.
10. Time Usage	• Dormant system, one-shot (e.g., missile), continuous use, fixed or variable use.
11. Maintenance Concept	• Wooden round, number of levels, etc.
12. High Risk/Failure Rate Items	• Do they limit performance? • Are they LRUs or SRUs? • Do they account for the majority of the performance risk of the equipment?
13. Performance Specifications	• Reliability • Maintainability • Functional • Design
14. Historical Data	• Test results • Operational data • Historical data from similar equipment
15. Built-In-Test	• Description • Requirements
16. Software	• Description • Characteristics
17. Relation to Other Equipment	• Is the equipment tightly integrated with other mission critical/significant equipment or does it operate in a self-contained manner?

PART I

EQUIPMENT CHARACTERISTICS	RIW	MTBF-VT	STORAGE VERIF.	LOGISTICS SUPPORT COST	MAX. PARTS COST	AVAIL.	CAPTIVE CARRY	MISSION DEPEND.	INCENTIVE AWARD
Correction of Deficiencies									
Conformance to Specifications									
Interim Contractor Support	+	+		+					
Cost Ceiling/Pro-Rata Cost									
Coverage									
Logistics Support Cost		+		=					
Maximum Parts Cost					=				
Repair/Replace Cost		+		=	=				
Reliability									
System	=	=		+					
LRU(s)/SRU(s)	=	=		+					
Availability/Readiness	=	=				+	+	+	
Performance Goal									
MTBF	=	=							+
Lifetime of Consumable Component									=
Lifetime of System/LRU									=
Dormant System Performance									
Storage Reliability			=			=		=	+
Mission Goals								=	+
Captive Carry							=		+
Availability			=			=			+
Program Management/Milestones									=
Other Specific Performance Goal									=
Turnaround Time Requirement	+	+							=

Figure 6.2.3-1. PPA Selection Matrix (PART I)

PART II

EQUIPMENT CHARACTERISTICS	RIW	MTBF-VT	STORAGE VERIF.	LOGISTICS SUPPORT COST	MAX. PARTS COST	AVAIL.	CAPTIVE CARRY	MISSION DEPEND.	INCENTIVE AWARD
Equipment Module									
System	+	+							
LRU(s) Only	+	+							
SRU(s) Only	-	+							
New Technology	-	+			+				
Operation Time Characteristics									
Dormant	≠	≠	=	≠	≠	=	=	=	
Continuous Use	+	+	≠	+	+				
Fixed Time Intervals	+	+	≠	+	+				
Variable	+	+	≠	+	+				
Operational Lifetime									
Consumable Components									
3-5 years (Short)	-			-					
3-5 years (Long)	+			+					
Length of Production Schedule									
3-5 years (Short)	-								
3-5 years (Long)	+								
Contract Type									
FFP	=								
CPFF	≠	≠	≠	≠	≠	≠	≠	≠	
CPIF	≠	≠	≠	≠	≠	≠	≠	≠	
FPIF	+								

Figure 6.2.3-1. PPA Selection Matrix (PART II)

PPAs with no symbol (blanks) beside the objective or characteristic should be overlooked.

To use the matrix, it is necessary to first identify the agreement objectives and equipment characteristics relevant to the program using the information collected in the previous step. Then, beginning with the rows of Part I, those agreement objectives which fit the program under examination are selected. The row of each selected objective is examined to find which PPAs are suitable to the program (denoted as "=" in the matrix) or which may be potentially relevant ("+"). For example, if a program has the objective of achieving a dormant system availability goal, then reading across that row shows that Storage Verification Guarantee, Availability Guarantee, and Incentive Award are options for the program.

After exercising Part I of the PSM to generate the list of potential PPAs, it is necessary to validate this list by executing Part II of the PSM. The second part of the PSM contains matrix diagnostics which are intended to eliminate those preliminary PPA choices that are not appropriate for the equipment and/or program characteristics given and to provide insight into the possible positive or negative effects these characteristics may have on the use of the PPA for the program.

To exercise Part II, the row corresponding to each equipment characteristic of the program is examined. When reading across the row, only the matrix elements in the columns of the PPAs selected in Part I of the matrix are relevant. For the above example, only the matrix elements in the Storage Verification Guarantee, Availability Guarantee, and Incentive Award columns are relevant. Each matrix diagnostic in the selected rows and columns is then checked to see whether the PPA should be excluded ("≠") or whether the equipment characteristic will have a positive ("+") or negative ("-") effect on the use of the PPA.

Continuing the above example, if the equipment under consideration had a CPFF contract type, reading across the CPFF Contract Type row shows a "≠" in the Storage Verification and Availability guarantee columns which indicates that these PPAs should be excluded whereas the blank in the Incentive Award column indicates ambivalence towards this PPA option. Specific interpretations for each diagnostic element in the matrix can be found in Reference 5 and can also be obtained from the Air Force Product Performance Agreement Center, Wright-Patterson AFB, Ohio.

To complete the preliminary PPA selection process it is also necessary to consider other PPA types that are not included in the PSM maintained in the PPA DSS. Figure 6.2.3-2 contains an expanded list of

Correction of Deficiencies (COD) and Inspection Group

- Inspection Clause
- Inspection of Supplies and Correction of Deficiencies Clause
- Correction of Deficiencies Clause
- Total System Performance Responsibility Guarantee
- Warranty of Supplies
- Warranty of Technical Data
- Rewarranty of Repaired/Overhauled Equipment
- Material and Workmanship Warranty
- Flying Hour Design Warranty

Reliability Group

- Reliability Improvement Warranty
- RIW with Mean Time Between Failure (MTBF) Guarantee
- MTBF Verification Test
- Chronic Line Replaceable Unit Guarantee
- Component Reliability Guarantee
- Reliability Guarantee
- Logistics Support Cost Guarantee
- Utility Function Warranty

Cost Ceiling Group

- Commercial Service Life Guarantee
- Logistics Support Cost Guarantee
- Maximum Parts Cost Guarantee
- Ultimate Life Warranty

Basic Maintenance Group

- Commercial Service Life Guarantee
- Repair/Exchange Agreement

Figure 6.2.3-2. PPA Types Grouped by Major Objective.

Dormant Systems Performance Group

- * Availability Guarantee
- * Captive Carry Guarantee
- * Mission Dependability Guarantee
- * Storage Verification Guarantee

Availability/Readiness Group

- * Availability Guarantee

Parameter/Performance Goal Incentives Group

- * Incentive Award Payments

* Asterisk Designates PPA Applicable to Dormant Systems.

Figure 6.2.3-2. PPA Types Grouped by Major Objective. (Continued)

PPA types characterized by major objective of the agreement with those applicable to dormant systems indicated with an asterisk (*).

To evaluate the applicability of the other PPA types, Reference 2 should be consulted. Appendix E to Reference 2 presents a brief overview of each PPA type including the following:

- PPA Objective
- Characteristics
- Applicability
- Description
- Measurement
- Result
- Advantages
- Disadvantages

By comparing the overviews with the information collected in the previous step, the applicability of a PPA type can be determined. Additional information from other sources such as the Air Force Product Performance Agreement Center, Wright-Patterson AFB, Ohio, should be consulted to aid in the selection of other PPA types.

After the initial set of PPA options for the program has been determined, the content of the selected PPAs must be checked for compatibility with the program before beginning the quantitative analysis. Primary aspects of the PPAs which should be closely reviewed include: (Reference 5.)

Maintenance Concept - Determine whether the PPA type is compatible with the program maintenance concept or does it require a different strategy. Determine whether it is possible to change the program to accommodate this different strategy or if it is possible to revise the PPA to accommodate the program maintenance strategy.

Data Collection Requirements - Identify the general data which is required to be measured and collected during the warranty/guarantee period and determine whether it is feasible to collect this data in terms of the program's logistic support strategy. Is a specific type of data collection system required for the PPA and if so does this exist in the DoD or will it have to be developed? (The data collection is one of the most important aspects of PPA implementation and must be thoroughly examined for feasibility within the program. Alternatives for implementing data collection systems, whether they are compatible with the time schedule of the program, and what the cost of the system is, must be examined.)

Testing Requirements - The PPA may include verification testing as part of the provisions. The testing requirements must be reviewed to ensure that they are feasible with respect to the program or if changes to program or PPA scheduling are necessary.

For each of the above aspects, the requirements of the PPA must be reviewed with respect to the program to:

- Ensure that the PPA is consistent with program activities and requirements.
- Identify requirements for implementing the PPA which must be provided by the program (either government or contractor).
- Identify alternatives for meeting these requirements (or determine whether it is impossible to meet them thereby rendering the PPA type infeasible for the program).

The list of PPA options resulting for this effort should then be quantitatively analyzed as described in the next section.

6.2.4 Analysis of Alternatives

The major portion of the quantitative analysis of a PPA centers on cost because the cost impact of a PPA is of major importance to both the Government and the contractor and because major benefits and risks can be stated in terms of cost. To perform the analysis it is useful to use a Cost Breakdown Structure (see Figure 6.2.4.1-1) and cost model as an overall framework. Such a framework will assist in identifying the relevant cost elements of a PPA and will show how to calculate these cost to perform the required analysis among the alternative PPA options. (Reference 5.)

For specific PPA types, certain other analytic technique are required to calculate its costs, benefits, and risks. For example, quantitative analysis may involve non-cost measures such as availability for an Availability Guarantee or mission completion for a Mission Dependability Guarantee.

Since it is always the case that there are at least two alternatives to be examined (e.g., PPA vs no-PPA), it is important to structure the analysis to make the selection among competing alternatives an integral part of it. The following procedure can be used to accomplish this:

- For each PPA option, identify the relevant cost elements which are affected by use of the PPA using the Cost Breakdown Structure for PPA analysis shown in Figure 6.2.4.1-1.

#	COST ELEMENT	AG	CCG	SVG	MDG	IA
	RESEARCH AND DEVELOPMENT					
1.	Validation					
1.1	Government					
1.2	Contractor					
2.	Full Scale Development					
2.1	Government					
2.2	Contractor					
	INVESTMENT					
4.	Government Program Management	X	X	X	X	X
5.	Prime Equipment Acquisition					
5.1	Production Hardware					
5.2	Production Spt. and Svc.					
5.3	Production Test and Eval.					
5.4	Initial Transport					
6.	System Installation					
6.1	System Provisioning/Modif.					
6.2	Installation Kit Spares					
7.	Support Equipment					
7.1	Hardware Acquisition					
8.	Initial Support Acquisition					
8.1	Initial Spares (Hardware)				X	
8.2	Software Investment					
8.3	New Item Entry					
8.4	Facilities					
8.5	Documentation					
8.6	Initial Training					
9.	Product Performance Agreement	X	X	X	X	X
	OPERATING AND SUPPORT					
10.	Corrective Maintenance	X	X	X	X	X
10.1	Below-Depot Level	X	X	X	X	X
10.3	Depot Level	X	X	X	X	X
11.	Scheduled Maintenance					X
11.1	Labor					X
11.2	Material					X
12.	Packaging and Shipping					

Figure 6.2.4.1-1. Cost Breakdown Structure for PPA Analysis

#	COST ELEMENT	AG	CCG	SVG	MDG	IA
	OPERATING AND SUPPORT (Continued)					
13.	Software Maintenance	X	X	X	X	X
14.	Inventory Storage					
15.	SE Maintenance					
16.	Documentation Maintenance					
17.	Sustaining Supply Support				X	X
17.1	Replenishment Spares				X	X
17.2	Supply System Management				X	X
18.	Recurring Training					

<u>Legend</u>:

AG: Availability Guarantee
CCG: Captive Carry Guarantee
SVG: Storage Verification Guarantee
MDG: Mission Dependability Guarantee
IA: Incentive Award

Figure 6.2.4.1-1. Cost Breakdown Structure for PPA Analysis. (Continued)

- Identify the analysis methodology and data requirements for the PPA types under consideration.

- Perform the required analyses to obtain the life-cycle costs, benefits, and risks of the PPA option including the no-PPA alternative.

- Compare the LCC estimates, savings/benefits estimates, and risk estimates of each of the PPA options.

- Assess the results and select PPA options for implementation.

An overview of these steps is presented in the following sections. Further details can be found in References 2 and 5.

6.2.4.1 Identification of Relevant Cost Elements

In comparing two alternatives, it is not enough to look at acquisition costs or Operating and Support (O&S) Costs for the first year or first few years. It is necessary to consider the costs of each alternative over the life of the system. Life cycle costing (LCC) is the tool most often used for comparisons over a systems life. It is used as a means to structure the analysis of the various PPAs by identifying the relevant cost elements of the PPA and by serving as a valid basis of comparison.

Not all cost elements need to be considered in the analysis. Only those costs that are directly impacted by the application of a PPA should be included. Those costs that would be the same regardless of which PPA option were implemented are not of importance to the PPA analysis, and should not be considered.

To identify the relevant cost elements for each PPA type, a common Cost Breakdown Structure (CBS) must be used. Figure 6.2.4.1-1 gives a Cost Breakdown Structure that includes all of the cost elements used in most LCC analyses and indicates the subset of cost elements typically relevant to the PPA types applicable to dormant systems identifield in Figure 6.2.3-2. The cost elements (row names) indicated with an "X" in the column headed by the PPA name are those that are relevant to the analysis of the cost of the PPA. Those elements without an "X" are considered to be non-relevant (i.e., not impacted by the use of the PPA).

6.2.4.2 Identification of Analysis Methodology and Data Requirements

Figures 6.2.4.2-1 through 6.2.4.2-5 summarize the analysis methodologies for each of the PPA types identified in Figure 6.2.3-2 as applicable to dormant systems. The figures are organized as follows:

AVAILABILITY GUARANTEE

Overview

The Availability Guarantee (AG) is applicable to dormant systems and is used to motivate the contractor to design and produce items with high operational readiness upon random demand. It normally applies to equipment where high reliability is critical and corrective maintenance is impractical or extremely costly. Availability is based upon random sampling checks from dormant storage over an extended period of time. Corrective action is taken as necessary to raise the level of availability when deficiencies are discovered. This PPA is not effective unless the equipment can provide positive indication of operability through random "go/no-go" checks.

Analysis Procedure

The analysis steps for the analysis required to evaluate the AG are:

- Identify the cost elements associated with the AG
- Calculate the LCC
- Compare this LCC to the other PPA options under consideration.

Data Requirements

The data requirements for the LCC analysis are those elements identified in the Cost Breakdown Structure in Figure 6.2.4.1-1 with an "X". This includes the PPA price which includes:

- "Go/No-Go" Testing Costs
- Data Collection/Evaluation Costs
- Administrative/Management Costs
- Corrective Action Costs
- Contractor Fee.

Figure 6.2.4.2-1. Availability Guarantee Analysis Procedure and Data Requirements Summary

CAPTIVE CARRY GUARANTEE

Overview

The Captive Carry Guarantee (CCG) is applicable to dormant systems periodically deployed in a captive carry mode and is used to motivate the contractor to design and produce items meeting specified captive carry specification requirements. Corrective action is taken as necessary to meet the specified performance levels when deficiencies are discovered. This PPA is not effective unless combined with a procedure for verification of the specification requirements that have to be met.

Analysis Procedure

Same as Figure 6.2.4.2-1.

Data Requirements

The data requirements for the LCC analysis are those elements identified in the Cost Breakdown Structure in Figure 6.2.4.1-2 with an "X". This includes the PPA price which includes:

- Specification verification costs
- Data collection/evaluation costs
- Administrative/management costs
- Corrective action costs
- Contractor fee.

Figure 6.2.4.2-2. Captive Carry Guarantee Analysis Procedure and Data Requirements Summary

STORAGE VERIFICATION GUARANTEE

Overview

The Storage Verification Guarantee (SVG) is applicable to dormant systems and is used to motivate the contractor to design an produce items with high storage reliability. The guarantee involves testing specified components of the item after a given storage period. Data from the test is used to compute a storage reliability parameter and compared to the guaranteed parameter level. Corrective action is taken as necessary to meet the guaranteed parameter level when deficiencies are discovered. The SVG PPA is not effective unless it is used in conjunction with a verification test.

Analysis Procedure

Same as Figure 6.2.4.2-1.

Data Requirements

The data requirements for the LCC analysis are those elements identified in the Cost Breakdown Structure in Figure 6.2.4.1-2 with an "X". This includes the PPA price which includes:

- Component testing costs
- Data collection/evaluation costs
- Administrative/Management Costs
- Corrective action costs
- Contractor fee.

Figure 6.2.4.2-3. Storage Verification Guarantee Analysis Procedure and Data Requirements Summary.

MISSION DEPENDABILITY GUARANTEE

Overview

The Mission Dependability Guarantee (MDG) is applicable to dormant systems and is used to motivate the contractor to design and produce items which attain specified mission goals (e.g., number of on-target hits, mission completion success probability etc.) where it is impractical or impossible to access the system during the mission. Corrective action is taken as necessary to meet the specified mission goal when deficiencies are discovered. This PPA is not effective unless combined with a procedure for verification of the specified mission goals that have to be met.

Analysis Procedure

Same as Figure 6.2.4.2-1.

Data Requirements

The data requirements for the LCC analysis are those elements identified in the Cost Breakdown Structure in Figure 6.2.4.1-2 with an "X". This includes the PPA price which includes:

- Mission goal verification costs
- Data collection/evaluation costs
- Administrative/management costs
- Corrective action costs
- Contractor fee.

Figure 6.2.4.2-4. Mission Dependability Guarantee Analysis Procedure and Data Requirements Summary.

INCENTIVE AWARD

Overview

The Incentive Award (IA) PPA is applicable to dormant systems and is used to motivate the contractor to design and produce items which meet Government objectives related to cost, performance, or schedule such as: unit cost goals, reliability goals, maintainability goals, readiness goals, performance goals, etc. The agreement may provide for an inventive payment to the contractor if goals are exceeded and/or a negative incentive if goals are not met. If multiple incentives are used it is necessary to ensure that they are compatible. The achievement by the contractor of one incentive goal should not be at the expense of another. To encourage beneficial tradeoffs, separate incentive awards should be used for each incentive goal of a multiple incentive PPA. A single incentive award should not be coupled to the achievement of multiple incentive goals.

Analysis Procedure

Once an incentive parameter is selected, it is necessary to perform statistical analysis to determine the set of values for which the contractor is neither penalized nor rewarded. This zone represents the "business as usual" range and is based upon technical risk, previously demonstrated capability, and desired capability. Among the most popular statistical techniques for accomplishing this are:

- Confidence Interval Analysis
- Risk Analysis

The dollar amount of the incentive payment awarded (1) depends on the available budget for the PPA and the worth of achieving the improved parameter levels, and (2) must be large enough for it to serve as a true incentive to the contractor.

Data Requirements

- Confidence Interval Analysis - The minimum data required for this analysis are high, low, and "most likely" values for the incentive parameters, from which data ranges for the desired level of confidence can be determined.

- Risk Analysis - The data required include (1) Government assigned risk factors for the parameter to be incentivized, and (2) the specified guaranteed parameter level.

Figure 6.2.4.2-5. Incentive Award Analysis Procedure and Data Requirements.

- PPA Overview

- Analysis Procedure and Associated Tools

- Data Requirements

A more detailed discussion of these and other PPA types are available in References 2 and 5 and from the Product Performance Agreement Center, Wright-Patterson AFB, Ohio.

6.2.4.3 Performing the Required Analyses

After having identified the analysis methodology and data requirements for the PPA types under consideration, the next step is to perform the required analyses to obtain the life-cycle costs, benefits, and risks of the PPA options including the no-PPA alternative. This section presents an overview of PPA analysis tools useful for accomplishing this task. The discussion of these tools is divided into the following categories:

- Life-Cycle Costing Analysis

- Reliability Analysis

- Cost/Benefit Analysis

- Risk Analysis

A more detailed discussion of these tools can be found in References 2 and 5.

6.2.4.3.1. Life-Cycle Cost Analysis

Life-cycle costing (LCC) is a method of calculating the total cost of ownership of equipment considering both the acquisition costs (Research and Development and Investment Phase Costs) and operating and support (O&S) costs. Acquisition costs include costs such as initial spares, initial training, installation, and the costs to purchase the items. O&S costs refer to the costs of operating and supporting the equipment such as maintenance costs, sustaining spares costs, support facilities costs, and recurring training costs.

Life cycle costing should be employed whenever a program's life exceeds more than one year. It explicitly accounts for the total cost of ownership of equipment through the use of discounting. Discounting is a technique of converting individual cash flows/costs spread over a period of time into present values which related the various flows to one another just as though they had occurred at the same period in time. (See Figure 6.2.4.3.1-1.) This technique yields a single LCC estimate for each competing option on the program providing a basis for comparing the options.

The major use of LCC in the analysis of PPA's is to assess the total impact of implementing a PPA upon a program's cost for the life of the equipment, and to evaluate the cost-effectiveness of the program's logistic support system given the existence of a PPA. While the life of the program will, in most cases, substantially exceed the time span of the PPA, the impact of the PPA on logistics support will be felt throughout the life of the program. LCC estimates must therefore include all years in a program's life for which relevant costs are incurred.

In conducting an LCC analysis or establishing an LCC baseline estimate for the various PPA options being evaluated, consideration should be given to LCC estimates already established for the program. The PPA LCC analysis should be consistent with established LCC estimates in the following areas as a minimum (Reference 5):

- Cost estimating methodology
- Parameters (system life, quantities, MTBF, etc.)
- Cost breakdown structure
- Data

This will ensure a consistent set of LCC estimates.

If an LCC model is currently being used on the program, it should be used for the analysis of PPA alternatives providing it meets the following criteria:

- Comprehensiveness - The model must contain a level of detail appropriate for the required analyses.
- Flexibility - The model must permit tailoring to allow inclusion of the necessary cost elements or levels of detail key to the PPA analysis.
- Controllability - The model must permit annual parameter changes to capture the cost impact of changes in parameters that occur during the program life cycle.

Case	Relationship
Time is not being considered	$C = P * Q$
Price and quantity vary with time	$C = \quad P_i * Q_i, \ i = 1, \ldots, N$
Inflating for future values	$C = \quad P_i * (1+p)^i * Q_i, \ i = 1, \ldots, N$
Discounting for present values	$C = \quad P_i *Q_i/(1+d)^i \ i = 1, \ldots, N$
Discounting inflating dollars for present values.	$C = \quad P_i * (1+p)^i * Q_t/(1+d)^i, \ i = 1, \ldots, N$

where,

C = Total Cost,	Q = Quantity,	p = Inflation Rate
P = Price,	N = Years,	d = Discount Rate

Figure 6.2.4.3.1-1. Cost Accounting Relationships in Life-Cycle Costing. (Reference 5.)

If the current LCC model does not meet these criteria, a new model must be chosen that does. Reference 9 describes the use of the RCA price parametric life cycle cost model for the analysis at PPA's. Additional LCC models that have been utilized for the analysis of PPA alternatives are described in References 5 and 10.

6.2.4.3.2 Reliability Analysis

Reliability (R(t)) is defined as the probability that a system will perform in an acceptable fashion, for a specified period of time (t), when used according to specified conditions. There are several ways to measure reliability depending upon the characteristics of the equipment and its intended use. The most frequently used measures in the analysis of PPA's applied to dormant systems are:

- Mean Time Between Failure (MTBF) -the number of hours between failures

- Failure rate - the inverse of MTBF

- Success Probability (R(t)) - usually expressed as $R(t) = e^{-t/MTBF}$ where e is the natural logarithm, and t is a specified period of time.

MTBF is very important since the ability to predict MTBF accurately is a key issue in PPA risk. (References 7 and 11.) The Council of Defense and Space Industries Association (CODSIA), in a letter to the Air Force in 1976, stated (Reference 11):

> "Until the hardware is tested in an operational environment, with typical operational users, and in all planned vehicles/platforms, etc., reliability is not 'reasonably predictable.'"

Calculations derived from textbook data sources such as MIL-HBDK-217 for operating periods and RADC-TR-85-91 for non-operating periods are useful for relative comparisons of alternative designs but they are not accurate estimates of field reliability under actual use conditions needed for PPA analysis. This is because the environmental factors used in these data sources represent an ideal state and do not reflect all of the randomness required for the real use environment (Reference 12).

Table 6.2.4.3.2-1 lists the data and information sources for failure data that are typically available during full scale development, test and evaluation, and operational program phases. The actual sources of data will vary according to the particular requirements of the program. For those systems in development where limited failure data

Program Phase	Data Source	Origin
Full Scale Development	• Reliability Demonstration Test	Contractor
	• Reliability Qualification Test	
	• Reliability Prediction	
Test and Evaluation	• Operational Test Data	Government
	• Combined Environments Reliability Test (CERT)	Contractor field reports
Operational	• Maintenance Data Collection System (e.g., D056)	Government
	• Base Level Records (e.g., AFTO Form 95s and 349s)	

Table 6.2.4.3.2-1 Reliability Data Sources (Reference 5)

exists, the best source is to use experience on analogous fielded systems. (Reference 5.) This is especially true for systems that will experience long periods of dormancy since life testing for dormant periods is impractical and the correlation of accelerated test results to actual field results is, in many cases, unclear.

An assumption of a constant failure rate, which is often made to simplify reliability calculations, may not be appropriate for PPA analyses. As shown in figure 6.2.4.3.2-1, this assumption is only valid in the mid-use life of the equipment. It may not be appropriate for PPA analysis purposes because the PPA generally covers the initial life of the equipment which may include some quality failures, and the period of decreasing failure rate during infant mortality (Reference 9.). This is especially true for dormant periods since the majority of non-operating failures are due to latent quality and workmanship defects. Experience on analogous fielded systems is again the best source of information in determining the appropriate failure rate to use. Another method using the Duane reliability growth model to predict the change in failure rate over the life of the PPA is described in Reference 5.

6.2.4.3.3 Cost/Benefit Analysis

Cost/Benefit analysis is a technique that employs net present value analysis to distinguish between two competing alternatives. Net Present Value (NPV) refers to the difference between the present value (i.e., discounted) costs of the two alternatives (see Figure 6.2.4.3.1-1). For PPA comparative analysis, the difference between the costs for two or more alternatives is a measure at the benefit (or cost avoidance) derived from selecting one alternative over another.

To perform costs/benefit analysis the following procedure should be used:

- Quantify benefits/costs in terms of dollars for each year affected by the PPA.
- Calculate present values for the annual dollar benefits/costs for each alternative (see Figure 6.2.4.3.1-1).
- Subtract the present value costs from the present value benefits for each alternative. This is the NPV.
- Compare the sum of the NPV's for each alternative. The alternative with the largest positive NPV is the preferred alternative.

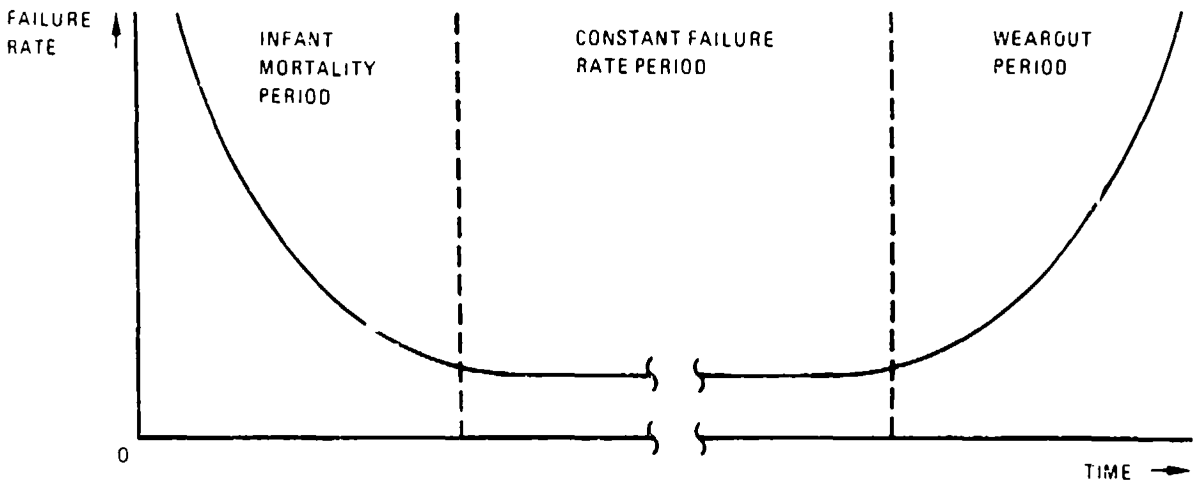

Figure 6.2.4.3.2-1. Example Reliability Curve

An example of this procedure from Reference 5 is shown in Figure 6.2.4.3.3-1.

The ratio of total present value costs to total present value benefits for a particular alternative, called the cost/benefit ratio, is sometimes used to select among alternatives. The project with the lowest ratio is considered the preferred alternative. The cost/benefit ratio is a measure of how effectively each dollar of cost is utilized to create dollar benefits and, as a result, will not necessarily lead to the same alternative preferred by merely comparing NPV's.

Prior to making a final decision based on NPV's and cost/benefit analysis, it is advisable to perform cost effectiveness and breakeven analysis to evaluate those areas where the decision may be switched from one alternative to the other. In the evaluation of the cost effectiveness of alternatives, the balance between system effectiveness (the ability of a system to meet both technical and logistics requirements) and total LCC is evaluated. The desired balance is dependent upon the weight that the program places on increments of system effectiveness vs. increments of LCC. For example, a 10% increase in availability that results in a 5% increase in LCC may be acceptable for one program but not another. Cost effectiveness is often measured as the ratio of the system effectiveness measure (e.g., availability) to the LCC. The cost effectiveness ratios for different alternatives are then compared to determine the preferred alternative.

The objective of breakeven analysis is to determine the point in time when an alternative moves from being not preferred to being preferred or vice versa. Such a point is called the breakeven point. Breakeven analysis highlights the differences between alternative choices by utilizing critical program characteristics (budget and schedule) as decision factors. The procedure for performing breakeven analysis is as follows: (Reference 5)

- Plot the cumulative annual present value LCC amounts for two PPA alternatives on the same axes with cost as the Y axis and time as the X axis. (See Figure 6.2.4.3.3-2.)

- Determine the crossover point for the two curves. This is the breakeven point.

- Identify the cost avoidance benefits after the breakeven point that accrue when the PPA with the least LCC is chosen. This is the area between the two curves to the right of the breakeven point.

Equipment A

Year n	Cash Flow Benefits	Cash Flow Costs	Discount Factor (10%)	Present Value Benefits	Present Value Costs
0		$15,000	0.0000		$15,000.00
1		6,000	0.9091		5,454.60
2	$ 5,000	3,000	0.8264	$ 4,132.00	2,479.20
3	12,000		0.7513	9,015.60	
4	16,500		0.6830	11,269.50	
5	25,800		0.6209	16,019.22	
6	23,000		0.5645	12,983.50	
Total	$82,300	$24,000		$53,419.82	$22,933.80

NPV = $30,486.02

Equipment B

Year n	Cash Flow Benefits	Cash Flow Costs	Discount Factor (10%)	Present Value Benefits	Present Value Costs
0		$20,000	0.0000		$20,000.00
1		12,000	0.9091		10,909.20
2	$ 4,000	6,000	0.8264	$ 3,305.60	4,958.40
3	13,000	5,000	0.7513	9,766.90	3,756.50
4	17,000	3,000	0.6830	11,611.00	2,049.00
5	22,000		0.6209	13,569.90	
6	20,000		0.5645	11,290.00	
Total	$76,000	$46,000		$49,633.30	$41,673.10

NPV = $ 7,960.20

Figure 6.2.4.3.3-1. Cost/Benefit Analysis Example. (Reference 5.)

- Judge the appropriateness of the PPA choice based upon considerations such as: the point in time at which breakeven occurs, the magnitude of the cost avoidance benefit, and the uncertainty associated with the PPA derived benefits for the years preceding and following the breakeven point.

6.2.4.3.4 Risk Analysis

In general, a risk analysis is required whenever there is uncertainty associated with the parameter estimates used to represent probable future values. Reference 5 identifies the following sources of risk (uncertainty) associated with the analysis of PPA alternatives:

- Estimates of MTBF, repair times, unit cost, repair cost, etc., made early in the acquisition cycle.

- Changes to the scope of the program (performance, quantity of items, schedule delivery dates, site activation dates, operating vs. non-operating time, etc.).

- Technical and technological problems (material or production problems, resource limitations, etc.).

- Uncertainty inherent in estimating parameters (omission of relevant parameters, problems in fitting models to data, the random nature of processes, etc.).

These risk sources must be analyzed and the results must be incorporated into the analysis of PPA alternatives in order to minimize the possibility that an alternative chosen as appropriate for the life of a system will in the future prove to be a poor choice.

In order to properly account for risk in the analysis of PPA alternatives, it is desirable to bound the risk associated with estimates of future parameter values. To do this, assumptions must be made about the magnitude of the error. The following sections describe three methods for bounding risk that are applicable to the analysis of PPA's. They are:

- Sensitivity Analysis
- Confidence Interval Analysis
- Beta Distribution Analysis

6.2.4.3.4.1 Sensitivity Analysis

Sensitivity Analysis is one technique for assessing the stability of a choice of alternatives where there is uncertainty associated with the data and assumptions. It is useful for determining the sensitivity of analysis results to variations in the input parameters and for determining the degree to which input parameters must change in order to effect a change in the preferred alternative.

In general, as the amount of data available about a program and system being evaluated increases, the uncertainty concerning future cost streams for the program decreases. The absense of data for specific program parameters however usually results in the use of high and low estimates for these parameters.

In performing sensitivity analysis, it is useful to have a baseline case for comparison purposes. For PPA analysis, reference 5 recommends using the no-PPA alternative as the baseline. The procedure for performing the sensitivity analysis is then as follows:

- Calculate the baseline LCC.
- Determine the range of the parameters to be changed. Do this for either all uncertain parameters or only identified cost drivers (i.e., parameters having a large influence on total cost).
- Calculate LCC estimates for best and worst case combinations of the parameters being changed for each alternative.
- Perform cost/benefit analyses (see section 6.2.4.3) and determine where changes in the preferred alternative occur.
- Select a preferred alternative based upon an assessment of the likelihood of the parameters changing as defined.

While this procedure provides a convenient method for evaluating the effects of parameter changes upon LCC and alternative choice, it does not, by itself, provide a quantified estimate of the uncertainty associated with a particular estimate or choice. The following two methods provide a means of quantifying this uncertainty.

6.2.4.3.4.2 Confidence Interval Analysis

Confidence interval analysis is a method of determining an interval which will include a parameter being estimated, such as MTBF, with a specified degree of certainty. The interval containing the parameter is referred to as the confidence interval and the specified degree of certainty that the interval will include the parameter is referred to as the confidence level. Confidence intervals are usually defined by two endpoints which are referred to as the lower limit (LL) and the upper limit (UL). They can, however, be defined by only one end point.

By giving a range (in probability) of where the true value of a parameter, such as MTBF, lies, confidence intervals permit the expression of uncertainty about the true mean value of the parameter population in terms of the bounds on the value. They also allow the testing of the validity of assumed values of the population parameters. Such testing is referred to as <u>hypothesis testing</u>.

Confidence interval analysis and hypothesis testing is applicable when sample data is available from which a parameter of interest is to be calculated. For example, failure data may be available from a sample test of a quantity of end items. Rather than merely calculate the average failure rate for use in the analysis and pricing of a PPA, an interval can be calculated from the same data. The advantage of using an interval instead of the single point average failure rate is that the interval provides information concerning the likelyhood of the actual failure rate falling within the interval while the single point value provides no information concerning how much error it is likely to contain.

A detailed discussion of confidence interval analysis and hypothesis testing is beyond the scope of this book. For a detailed discussion of the application of confidence interval analysis to the analysis of PPA alternatives, refer to Reference 5.

6.2.4.3.4.3 <u>Beta Distribution Analysis</u>

Beta distribution analysis is a method borrowed from PERT/CPM (Program Evaluation Review Technique/Critical Path Method) used to account for uncertainty in estimates. In order to account for uncertainty, the method requires three estimates (optimistic, most probable, and pessimistic) for each parameter. They are defined as:

- <u>Optimistic Estimate (a)</u> - the value of the parameter if all assumptions and conditions occur in an ideal manner.

- <u>Most Probable Estimate (m)</u> - the value of the parameter most likely under normal conditions.

- <u>Pessimistic Estimate (b)</u> - the value of the parameter if worst case conditions occur.

The method gets its name from the assumption that the uncertainty described by the estimates is best defined by a beta probability distribution (Reference 13).

Based upon the three estimates, the mean (expected value) and variance of a parameter (x) being estimated are defined as:

$$\text{Mean }(x) = \frac{a + 4m + b}{6}$$

$$\text{Variance }(x) = \left(\frac{b - a}{6}\right)^2$$

The expression for the mean is a result of assuming that the three estimates describe a beta probability distribution. The expression for the variance is based on the idea that a standard deviation is approximately 1/6th of the difference between the extreme values of the distribution and that the variance is merely the square at the standard deviation.

After calculating the mean and variance for each parameter, the following relationships from reference 14 are used to calculate the mean and variance for the sum and product combinations of the parameters (e.g., X and Y) necessary to complete the PPA analysis. These relationships assume that the parameters are not correlated.

Sum

Mean [X + Y] = Mean [X] + Mean [Y]
Variance [X + Y] = Variance [X] + Variance [Y]

Product

$$\text{Mean } [XY] = \text{Mean } [X] \times \text{Mean } [Y]$$

$$\begin{aligned}\text{Variance } [XY] = {} & (\text{Variance } [X] \times \text{Variance } [Y]) \\ & + (\text{Mean } [X]^2 \times \text{Variance } [Y]) \\ & + (\text{Variance } [X] \times \text{Mean } [Y]^2)\end{aligned}$$

Based upon the central limit theorem, the resulting mean and variance values can be assumed to follow a normal distribution and the probability that a value lies within a certain range can be calculated using the standard normal deviate and a table of the normal probability distribution (Reference 13.) An example of this method is shown in figure 6.2.4.3.4.3-1.

6.2.4.4 Final PPA Selection

After examining the identified PPA options and analyzing their impact on the program, a final determination of which PPA option(s) to apply must be made. This involves comparisons across the PPA options in the following areas (Reference 5):

- PPA Costs

	Estimates Optimistic (a)	Most likely (m)	Pessimistic (b)	Mean	Variance (VAR)
Equipment X Failures Per Year in Storage [F(X)]	2	5	10	5.33	1.78
Equipment Y Failures Per Year in Storage [F(Y)]	6	12	24	13.00	9.00
Cost to Repair X [CR(X)]	$ 5,000	$10,000	$25,000	$12,500	11,111,111 Dollars ^{2}
Cost to Repair Y [CR(Y)]	$10,000	$25,000	$55,000	$27,500	56,250,000 Dollars ^{2}

Total Repair Cost = [F(X) x CR(X)] + [F(Y) x CR(Y)]

Mean Total Repair Cost Per Year in Storage:

Mean [F(X) x CR(X)] + Mean [F(Y) x CR(Y)]
= (Mean [F(X)] x Mean [CR(X)]) + (Mean [F(Y)] x Mean [CR(Y)])
= (5.33 x $12,500) + (13.00 x $27,500)
= $424,125

Variance of Total Repair Cost Per Year in Storage:

VAR [F(X) x CR(X)] + VAR [F(Y) x CR(Y)]
= (VAR [F(X)] x VAR [CR(X)]) + (Mean $[F(X)]^2$ x VAR [CR(X)])
+ (VAR [F(X)] x MEAN $[CR(X)]^2$) + (VAR [F(Y)] x VAR [CR(Y)])
+ (Mean $[F(Y)]^2$ x VAR [CR(Y)]) + (VAR [F(Y)] + Mean $[CR(Y)]^2$)

Figure 6.2.4.3.4.3-1. Example Beta Distribution Analysis.

Variance of Total Repair Cost Per Year in Storage: (Continued)

$$= [1.78 \times 11{,}111{,}111 \text{ Dollars}^2] + [(5.33)^2 \times 11{,}111{,}111 \text{ Dollars}^2]$$
$$+ [1.78 \times (\$12{,}500)^2] + [9.00 \times 56{,}250{,}000 \text{ Dollars}^2]$$
$$+ [(13.00)^2 \times 56{,}250{,}000 \text{ Dollars}^2] + [9.00 \times (27{,}500)^2]$$
$$= 1.74323 \times 10^{10} \text{ Dollars}^2$$

Probability Actual Annual Repair Cost is not Greater Than $600,000 [P($600,000)]

$$\text{Standard Normal Deviate (Z)} = \frac{\$600{,}000 - \text{Mean Repair Cost}}{(\text{Repair Cost VAR})^{1/2}}$$

$$= \frac{\$600{,}000 - \$424{,}125}{132{,}031.44}$$

$$= 1.33$$

From a table of the normal probability distribution,

$$P(\ \$600{,}000) = \underline{0.908}$$

Figure 6.2.4.3.4.3-1. Example Beta Distribution Analysis. (Continued)

- Life-Cycle Costs
- Benefits
- Risks
- Effectiveness in reducing risk, achieving program goals (e.g., motivating the contractor to achieve higher levels of performance for his equipment).
- Cost effectiveness for the program

In addition to these areas, careful consideration must be given to any possible adverse effects a particular PPA may have on other program areas. For example, the dedication of incentive money on a captive carry guarantee may take resources from and possibly weaken other areas. A PPA may also give a contractor an unintended incentive to cut corners in other program areas, such as reducing the effectiveness of BITE to reduce the probability of BITE detected failures under the PPA.

As stated in section 6.1, effective PPAs must be simple, focused on the primary objectives to be obtained, enforceable, affordable in relation to potential benefits, and shouldn't cause disruption to existing military systems and procedures. Of all the areas to be considered in the final selection of which PPA options to apply, the most important one is the cost effectiveness for the program. If a cost effective PPA cannot be structured for a program then a PPA should not be applied to the program. Title 10, Section 2403 of the United States Code specifically provides for the waiver of the PPA requirement in the event that it is determined that it is not in the interests of national defense or is not cost effective.

After the final decision has been made, the contractual provisions for any selected PPA options must be formulated. This is covered in the following section.

6.2.5 PPA Structuring

There is no "cookbook" approach to structuring a PPA. Each program has unique needs, characteristics, and objectives that must be carefully considered in order to structure an effective agreement. However, an effective agreement will, in general, contain certain attributes. They are (Reference 5):

- Protect the interests of both the government and the contractor
- Contain tightly defined terms and conditions

- Minimize government costs

- Quantify risks to government contractors

- Contain specific performance parameters related to program objeccives and mission

- Specify data requirements, test procedures, analysis, and evaluation requirements.

The actual writing of the sections of a PPA can be a very demanding task. PPAs, however, generally include certain sections to cover issues common to all agreements. These sections are described in figure 6.2.5-1.

In structuring a PPA, it is very helpful to search out experience on similar programs. PPA clauses from other programs should be examined for their applicability and to identify what should be included and to obtain examples of contractual wording. Table 6.2.5-1 presents typical performance measures for each of the PPA types identified as applicable to dormant systems. Other program offices with similar programs and/or PPAs should be contracted for input on provisions used and lessons learned to see where provisions should be added or revised to avoid repeating past mistakes. Other sources for lessons learned information are the Lessons Learned Programs of the Joint AFLC/AFSC and PPAC. In addition, the PPAC library at Wright-Patterson AFB, Ohio, contains PPA Application Criteria including PPA Structuring Guidelines and Management and Implementation Guidelines.

It is beyond the scope of this book to provide specific contractual provisions for each of the PPA types identified in section 6.2.3 as applicable to dormant systems. As previously stated, each program has unique needs, characteristics, and objectives that must form an integral part of any resulting agreement. The general guidelines presented here provide a framework for structuring an effective agreement. The details must be worked out on a program by program basis.

6.3 PRODUCT PERFORMANCE AGREEMENT MANAGEMENT

The management of PPAs applied to equipment procurements is a key factor in determining the ultimate cost-effectiveness of these agreements. In order to be cost-effective, the government must be able to manage the PPA reasonably; that is, have the ability to collect the data on the items to determine if they are still within the PPA period before the PPA can be enforced. The cost and effort to accomplish this must not outweigh the benefits of the PPA. The effects of improper management of a PPA can be severe with the government possibly loosing many (or even all) of the rights gained under the PPA.

PPA Section	Description
1. Introduction	States the Government's objectives for the program including such topics as the system/equipment type, PPA objectives, and the PPA period.
2. Definitions	To avoid ambiguity, all terms should be defined and used consistently throughout the contract, however, existing official terms do not need to be redefined unless they are being tailored to provide consistency.
3. Contractor Warranty	Generally lengthy but very important in minimizing government and contractor risk. The following areas should be covered: • Identification of equipment covered. • The specific performance parameters covered with the necessary equations and models. In general, separate sections are usually written providing guarantees that the item provided will: (1) conform to the design and manufacturing requirements in the contract, (2) be free from defects in material and workmanship at the time of delivery, and (3) conform to the essential performance requirements identified. • The period of the PPA. • Intended environment. • Maintenance philosophy for organic and contractor support.
4. Contractor Obligations	This section should include terms and conditions concerning the following: • Identification plates designating serial number, part number, installation dates. • Decals or seals with dates for warranty tracking. • Bonded storage areas.

Figure 6.2.5-1. Sections of an Effective PPA.

PPA Section	Description
4. Contractor Obligations (Cont.)	• Engineering Change Proposals (ECPs) either at no cost to the Government or shared cost between Government and contractor. • Spares levels, requirements, compensation. • Data tracking. • Transition period from PPA period to post-PPA period, including peculiar support equipment, publications, manuals, and training.
5. Government Obligations	This section should describe Government obligations in sharing the responsibility and risk for a PPA including: • Shipping costs and facilities for failed units and spares. • Provision of specified test equipment, Government Furnished Equipment. • Organic maintenance and support • Participation in failure verification procedure. • Administration and monitoring of PPA contractor obligations. • Evaluation of PPA-related ECPs or design changes.
6. Notification of Breach	Notification must be timely, complete, and accurate. Notification can be given to the contractor by a Government representative advising a contractor field representative, a formal contracting officer letter or in writing through an appropriate service report. The acceptable method should be specified. The time for notification of breach should be based upon the time necessary for the Government to: (1) discover problems, (2) take administrative steps to report problems, and (3) discover and report defective replacements.

Figure 6.2.5-1. Sections of an Effective PPA (Continued)

PPA Section	Description
4. Contractor Obligations (Cont.)	• Engineering Change Proposals (ECPs) either at no cost to the Government or shared cost between Government and contractor. • Spares levels, requirements, compensation. • Data tracking. • Transition period from PPA period to post-PPA period, including peculiar support equipment, publications, manuals, and training.
5. Government Obligations	This section should describe Government obligations in sharing the responsibility and risk for a PPA including: • Shipping costs and facilities for failed units and spares. • Provision of specified test equipment, Government Furnished Equipment. • Organic maintenance and support • Participation in failure verification procedure. • Administration and monitoring of PPA contractor obligations. • Evaluation of PPA-related ECPs or design changes.
6. Notification of Breach	Notification must be timely, complete, and accurate. Notification can be given to the contractor by a Government representative advising a contractor field representative, a formal contracting officer letter, or in writing through an appropriate service report. The acceptable method should be specified. The time for notification of breach should be based upon the time necessary for the Government to: (1) discover problems, (2) take administrative steps to report problems, and (3) discover and report defective replacements.

Figure 6.2.5-1. Sections of an Effective PPA (Continued)

PPA Section	Description
7. Remedies	This section should clearly define the actions to be undertake by the contractor in the event of a breach and should include: • The scope of the corrective actions for which the contractor will be responsible. • The required turnaround time for a warranted item including steps to be taken if turnaround times are not met. • A "disputes" clause identifying what is to be done in cases of disputes regarding the applicability of the PPA.
8. Exceptions and Conditions	This section should contain exceptions and conditions voiding the applicability of the PPA. They should be kept to a minimum and should only include those areas outside the contractor's control such as: (1) improper operation or maintenance by Government personnel, (2) acts of God, and (3) combat damage.
9. Data Requirements	The enforcement of a PPA is highly dependent upon accurate and complete data reporting. This section should clearly define: • Types of data to be collected. • Data reporting format, frequency, forms, etc. • Data storage and availability to the Government. • Analysis of data collected, reports to government, evaluation by government.

Figure 6.2.5-1. Sections of an Effective PPA (Continued)

PPA Section	Description
10. Test Plan	Dormant systems typically use a test plan over a specified period to check the reliability and availability of the system over time. The test plan section should include: (1) test articles and production lots to sample from, (2) test sample size, (3) test interval including dates and duration, (4), test location, (5) personnel responsible for testing, data collection, monitoring, and test result analysis, (6) retest provisions, (7) failure definition, and (8) performance measurement definition.
11. Contractor Access To Government Maintenance and Operational Facilities	This section should define the contractor's right to reasonable access to the facilities and records that apply to covered items. However, the contactor should not have the right to interfere with the facilities, operations or unduly burden the government with data requests.
12. Liability Cap	Limitations on liability have generally been used as a means of restricting the contractor's exposure to a level that will keep the price of the PPA reasonable. If used it should be high enough to retain the motivation for the contractor to want to eliminate problems and should reflect the degree of risk actually assumed by the contractor.

Figure 6.2.5-1. Sections of an Effective PPA (Continued)

Table 6.2.5-1. Typical Performance Measures for Dormant System PPAs.

PPA Type	Performance Measure	Example Criteria	Example System
Availability Guarantee	Storage Availability	Availability is calculated as: $SA = \frac{GS + GC}{TA} \times 100$ where: SA = Storage Availability GS = Ground Simulation Test Successes GC = Ground Checkout Test Successes TA = Total Attempts (Ground Simulations and Ground Checkouts) Corrective action (no-cost ECP's, etc.) if SA 95%. Incentive payment if SA 97%.	Air Launched Cruise Missile
Captive Carry Guarantee	Captive Carry Mean Time Between Failure (MTBF)	The system shall demonstrate a Captive Carry MTBF of at least 36 hours. The contractor's action threshold shall be 1530 confirmed failures over the warranty period based upon a defined utilization scenario. The action threshold will be adjusted for substantial deviation from the defined utilization scenario.	Maverick (Ref. 15)
Storage Verification Guarantee	Storage Reliability	95% of the systems tested shall pass the test. The contractor's action threshold shall be 219 confirmed failures as encountered on no more than 2 periodic checks per equipment during the warranty period.	Maverick (Ref. 15)

Table 6.2.5-1. Typical Performance Measures for Dormant System PPAs. (Continued)

PPA Type	Performance Measure	Example Criteria	Example System
Storage Verification Guarantee	Stockpile Reliability Test - Ground Test	The contractor shall repair all failures occuring during the ground test portion of the stockpile reliability test program over the warranty period. The contractor shall perform a detailed failure analysis and if the problem is indicative of a generic problem affecting other units, the contractor shall repair all items covered under the warranty.	Pershing II (Ref. 16)
Mission Dependability	Flight Test Success	A sample of X items are fired from a lot of items in storage for Y years. If less then Z are successful, the contractor must fix the lot.	Copperhead
Mission Dependability Guarantee	Prelaunch Reliability	93.5% of the systems tested will not fail during the period from checkout through all mission phases through depression of the weapon release button. The contractor's action threshold will be those repair actions in excess of 16 confirmed prelaunch reliability failures during a maximum of 375 launches in the warranty period.	Maverick (Ref. 15)
Incentive Award	Waivers and Deviations	The target fee shall be adjusted to reflect the incentive fee gained or lost as a result of the contractor's performance in delivering non-conforming hardware. The measurement of such performance shall be a function of the number of discrepancies granted category A or B Waivers or Deviations. A category A waiver or deviation shall count as two points and a category B waiver or deviation shall count as one point. The target fee is 758 penalty points with maximum gain at 0 penalty points, and maximum loss occurring at 1040 penalty points, with interim values adjusted linearly.	Trident II (Ref. 17)

Perhaps the most important step in making sure that a PPA is administered properly concerns training. If a PPA isn't administered properly, potential benefits are lost. Much waste can occur if maintenance, supply, or contract administration personnel; management; and others are nct given complete information about what is covered by the PPA and the Government's and Contractor's obligations under the PPA. All affected personnel should be trained concerning their respective duties regarding the PPA. Since field personnel are the first to encounter potential PPA claims, they should, as a minimum, be able to:

- Identify the covered item.

- Report the breach of a PPA to the proper activities.

- Start the prescribed action leading to the remedy.

To make the identification of covered items easier they should be suitably marked with some form of identification indicating that they are covered by a PPA. Such marking could be the word "Warranted" on the item of just "W" before the part number (Reference 1.). The marking instructions should be clearly defined in the contract.

It is important to define the tracking system to be used and how data are to be interpreted. This should be addressed in the development of the PPA and its management plan. Imposing a PPA without consideration of the tracking can lead to future problems and discrepancies between the way a PPA is actually managed and the basis on which the PPA analysis was made. The ideal situation would be for items to be tracked within a data system which is programmed to permit use of a PPA symbol or message while the item is covered under the PPA and automatically delete the symbol or message when the PPA coverage period expires. (Reference 1.)

Technical data and manuals should identify items covered by PPAs and the duration of the PPAs. Equipment log books and record cards should also state that an items is covered by a PPA and should include the effective period of the PPA.

In monitoring and assessing PPAs, costs for effort expended on PPA breach corrections should be segregated by both the contractor and government. All PPA actions taken by the contractor should be reported according to contract instructions. Each PPA action should be documented from the time a breach is discovered to the final disposition of the corrective actions. These data are necessary to evaluate future PPA proposals and for making a final assessment of the effectiveness and efficiency of the PPA.

6.4 REFERENCES

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APPENDIX A

RELIABILITY CHECKLIST

RELIABILITY CHECKLIST SECTIONS

1.0 GENERAL DESIGN CRITERIA

	ADE-QUATE	INADE-QUATE	N/A
1. Are the requirements for performance, signals, environment, life, and reliability established for each unit?			
2. Has the theoretical reliability or MTBF of the unit based on the actual application of the parts been determined?			
o Comparison made with reliability goal?			
o Provision for necessary design adjustments?			
3. Has the item or system been designed for ease of production and assembly, maintenance, inspection?			
4. Have factors of handling, transportation, packaging, and environments, other than the specified operational environments, been taken into account?			
5. If so, can the proposed design be considered as optimized under existing conditions and restraints?			
6. Have trade-off studies been conducted and completed in particular with respect to the following areas:			
o Performance?			
o Reliability?			
o Safety?			
o Circuit Design?			
o Power Consumption?			
o Packaging and Integration with other systems?			
o Weight?			
o Cost?			

2.0 RELIABILITY CRITICAL PARTS

Reliability critical parts are defined in the following paragraphs. These paragraphs should be used as a check list to determine if such parts have been identified and treated as noted.

Critical items are those whose failure would significantly affect mission success. Critical items include, but are not limited to, those identified by reliability, maintainability, safety, and human factors analyses. As soon as a critical item is identified, appropriate steps will be taken to assess the risks involved.

The criteria for defining critical items are:

- o Failure effect on safety.
- o Failure effect on mission accomplishment.
- o Need for special handling or storage.
- o Long lead-time.
- o High Cost.
- o Failure effect on maintenance burden.
- o Limited life.
- o High technical risk, i.e., the use of unproven technology.
- o Limited availability.

Critical items are generally best handled on a case-by-case basis. For example...

	ADE-QUATE	INADE-QUATE	N/A
1. Items which require special handling or storage will be reviewed to see if special containers, etc., are necessary.			
2. Items whose failure might impose a high maintenance burden will be examined from the viewpoint of reducing mean-time-to-repair, improving mean-time-between-failure, or generally improving overall maintainability.			

	ADE-QUATE	INADE-QUATE	N/A
3. Limited life items will be avoided to the greatest extent possible. If unavoidable, means to overcome this problem would be investigated by operating the part at a reduced stress level if feasible, if this does not impair performance.			
4. High risk technology will be avoided to the maximum extent possible. If its use is unavoidable, more conventional design concepts will be made available as a backup.			
5. Items with limited availability will be avoided. If this is not possible, arrangements will be made to assure that the item will be produced for as long as it will be required.			

3.0 ELECTRICAL CIRCUITS

	ADE-QUATE	INADE-QUATE	N/A
1. Have the operating and non-operating failure rates of the circuit been compiled, using approved part failure rates for the expected circuit application?			
2. Has the application of redundant circuits been considered as a means of increasing reliability?			
3. Have adjustments been minimized?			
4. Are elapsed time indicators installed in major components?			
5. Have self-testing or monitoring features been isolated wherever possible to prevent their causing failure of basic circuit functions?			
6. Is the circuit stable over the entire operating and non-operating range?			
7. Have design features been incorporated to suppress parasitic oscillations?			
8. Have the effects of long-term non-operating periods on each component, circuit, and assembly been considered?			
9. Have the effects of power on/off cycling on each component, circuit, and assembly been considered?			

4.0 ELECTRICAL PARTS

	ADE-QUATE	INADE-QUATE	N/A
1. Has shelf life of parts chosen for final design been determined?			
2. Have limited life parts been identified, and inspection and replacement requirements specified?			
3. Have critical parts which require special procurement, testing, and handling been identified?			
4. Has the selection of electronic component parts been limited to parts that have known or predictable parameter variations, whether resulting from purchase tolerances, soldering, environmental stresses, or aging?			
5. Has the use of environment sensitive parts been avoided wherever possible?			
6. Have tolerance effects, including those due to environment, been considered on all critical part parameters?			
7. Are all parts applied within their electrical and environmental ratings?			

5.0 MECHANICAL DESIGN

	ADEQUATE	INADEQUATE	N/A
1. Has adequate tolerance analysis been applied to the mechanical function of the design? (This includes not only checking of basic design tolerances but calculation of functional variations with expected environmental extremes mechanical error analysis).			
2. Has adequate lubricant life been ensured and have potential adverse effects of lubricants on other system components been eliminated?			
3. Has the danger of hydrogen embrittlement been considered in the use of highly treated steels and alloys?			
4. Have flexible parts, or flexible hoses and conducts, been routed in a way such that specified bend-radii and other installation limitations have not been exceeded?			
5. Has a worst-case adverse tolerance stackup been performed for each critical mechanical interface?			
6. Will tolerances remain within specified limits at extreme temperature?			
7. Has protection from mechanical abuse by the use of suitable mechanical protection techniques (packaging, mounting, and structural) been incorporated?			
8. Have either of the following been utilized to enable equipment to withstand the shock or vibration environment:			
o Vibration isolators and/or shock mountings?			
o Design to withstand the mechanical stress?			
9. Have any of the following corrosion techniques been utilized on exposed equipment:			
o Corrosion resistant materials?			

	ADEQUATE	INADEQUATE	N/A
o Plating and protective finishes?			
o Dissimilar metal contact avoidance?			
o Environmental control (water entrapment prevention, atmospheric moisture removal, etc.)?			
10. Has electrolytic action under specification extremes of humidity & temperature been minimized?			
11. Have the effects of differential pressure on leakage & on system/equipment configuration itself been considered?			
12. Have adequate performance functional and dimensional tolerance analyses been performed? Did this include:			
o Checking of basic design tolerances?			
o Calculation of functional variations for expected environmental extremes (mechanical error analysis)?			
13. Have structural materials and their conditioning and temper been selected to avoid possible stress corrosion?			
14. Have the combined effect of load and temperature induced stresses been considered for materials and material-conditions susceptible to creep or plasticity?			
15. Have major structural joints and bonds been prepared and tested under controlled conditions? Has this included:			
o Preparation under controlled and continuously monitored and recorded conditions and environments?			
o Verification of adequate quality by nondestructive inspection, including standard methods such as x-ray, dye-penetrant, magnetic particle, ultrasonic, and infra-red tests?			

	ADE-QUATE	INADE-QUATE	N/A
o Verification by destruction testing of test samples or coupons prepared and conditioned under identical conditions with the corresponding joints?			
16. Has the proper bolt-torque been specified where required? This also applies to all stud mounted devices?			
17. Have provisions been made to lock and secure all fastener elements against operating and non-operating conditions which tend to reduce their functional holding force?			
18. Have proper fasteners been employed to satisfy EMI and drip-proof requirements?			
19. Have the effects of outgassing products on component parts been considered and properly controlled?			
20. Has the existence of residual stresses introduced during material manufacture and conditioning and during subsequent storage been considered?			
21. Has the possibility of flaking, spalling and of fretting corrosion of structural elements been considered?			

6.0 PHYSICAL DESIGN AND LAYOUT

	ADE-QUATE	INADE-QUATE	N/A
GENERAL			
1. Have the package interfaces and subblock and subassembly break points been designed with the maintenance philosophy in mind?			
2. Has adequate consideration been given to ease of inspection and testing?			
ELECTRICAL AND ELECTRONIC LAYOUT			
3. Has the part spacing ensured:			
o The spacing necessary to reduce distributed capacitance and coupling between parts or part and chassis surfaces in critical electrical circuits?			
o Satisfactory application of harnessing branches, wiring leads, & service loops to part terminals, tie-points and posts?			
o Safe terminal and connection clearances to prevent arcing or leakage under all environmental conditions?			
o Sufficient spacing to permit proper part-lead-forming, strain relief, and component-to-component spacing?			
o Sufficient clearance to permit application of test leads without short circuiting of part leads?			
4. In general, have parts been positioned to avoid lead lengths that are either too long or to short for good layout practice?			
PRINTED CIRCUIT LAYOUT			
5. Is the thickness of the conformal coating controlled to prevent overstress or breakage of components?			

	ADE-QUATE	INADE-QUATE	N/A
6. Has a qualified base-laminate material that will remain dimensionally stable in soldering, that has low moisture absorption, and good electrical and mechanical properties been specified for the circuit board?			
7. Are flush mounted parts (flat packs) protected to prevent penetration of conformal coating under parts that can cause breakage of component leads?			
ELECTROMECHANICAL, MECHANICAL, AND MISCELLANEOUS LAYOUTS			
8. How might the design be modified to improve reliability, and would this compromise such factors as performance, cost, weight, availability, schedules, maintainability, etc.?			
9. Has the item or system been designed for ease of production, assembly, maintenance, and inspection?			
10. Have handling, transportation, packaging and environments other than the specified operational environments been taken into account?			
WIRING AND CONNECTOR LAYOUT			
11. Have all interconnections and cables been arranged so they do not block removeable units or fasteners?			
12. Is wiring mechanically secure against breakage, chafing, or other vibration and shock damage that might occur in the expected environment?			
13. Has wiring or cabling that is run through holes in partitions, shields, etc. been protected by grommets or rolled edges?			

	ADE-QUATE	INADE-QUATE	N/A
14. Is wiring that passes between two structural members mechanically flexible and securely clamped to each member with sufficient slack to prevent mechanical strain?			
15. Have specified minimum or less than minimum wire and cable bend radii been permitted in the layout, especially for RF cable?			
16. Have connectors in areas of heavy moisture, dust, fuel and other fluid seepage, etc. been protected?			
ELECTRONIC CHASSIS, CABINETS, AND EQUIPMENT ENCLOSURES			
17. Has the degrees of enclosure reflected the environmental requirement, the electrical shielding requirement, & the requirements imposed by human factors?			
18. Have qualified materials been selected on the basis of strength, weight, electrical factors, producibility, & resistance to the expected environment (humidity, fungus, etc.)?			
19. Have all component boards, terminal boards, and other part-mounting subassemblies using insulators been designed using suitable materials to facilitate input and output wiring, maintain electrical properties and strengths, and provide stable part mounting under all expected environments?			
20. For airborne and space equipment, has the use of connectors been limited to necessary intercomponent applications, where length and complexity make direct wiring impractical? (Multiple connector contacts contribute to system unreliability, especially where shock and vibration environments exists).			

	ADEQUATE	INADEQUATE	N/A
21. Has the design of covers and closures included:			
o Provision of interlocks and automatic disconnects for high-voltage areas?			
o Identification of the items or compartments covered?			
o Easy access for tool application?			
o Permanent attachment of removable closures, plugs, and small covers?			
22. Has a keying system been employed to prevent faulty interchanging of circuit boards?			
23. Has proper electrical grounding and/or bonding been provided across corrosion protected surfaces, mechanical interfaces, etc.?			
HARDWARE AND MISCELLANEOUS			
24. Have part mountings, fasteners, and assembly items in general used hardware suitable for the environmental requirements, and have the following design goals been met:			
o Adequate quantities and strengths of "black box" hold-down fasteners?			
o Sufficient clearances around and above fasteners?			
o A minimum of inaccessible or blind fasterners?			
o Adequate locking devices for the mechanical environment?			
o No dissimilar metals in contact, or suitable protection if this must be done?			

	ADE-QUATE	INADE-QUATE	N/A
o Similar types of fasteners in similar applications, reducing the number of tools required?			
o Specification of torque requirements?			
o Dimensionally correct hardware for the application? (Example: lengths of screws, proper openings, & proper contours on spring clips, etc.?			
25. Are materials and finishes consistent with intended use?			
MISCELLANEOUS			
26. Have effective radio-frequency-interference-suppression measures been incorporated in the design, including:			
o Grounding of the chassis or frame in accordance with good low-resistance grounding practices?			
o By passing of all shock mounts with a ground conductor?			
o Shielding of openings in the external wrapper or enclosure?			
o Use of noncommutating (brushless) motors for blowers and other applications where possible?			
o Use of metal bonding gaskets, under positive pressure, on all access doors, drawers, and removable covers?			
o Integral shielding of all oscillator compartments?			

7.0 ENVIRONMENTAL DESIGN

	ADE-QUATE	INADE-QUATE	N/A
GENERAL			
1. Has the physical design ensured satisfactory operation in or protection against all the environments to be encountered during the desired equipment life?			
2. Have the relative advantages and disadvantages of designing for operation in the environment or protection against the environment been weighed (package sealing versus environment-resisting parts)?			
3. Have the effects of the nonoperating environment on electronic and mechanical parts been considered (especially nonreversible effects)?			
4. Have the effects of the expected environments on the part failure rates used in equipment reliability analysis been reviewed?			
5. Have corrosion resistant materials or protective finishes been provided where required?			
6. Have the effects of environmental factors on material properties been considered? Has this included:			
o Temperature cycles and fluctuations?			
o Corrosive atmospheres and solid particle contaminants?			
o Humidity?			
o Radiation?			
o Life?			
o Fatigue?			
o Creep & Stress?			
o Embrittlement?			

	ADE- QUATE	INADE- QUATE	N/A
o Sublimation?			
o Melting?			
o Freezing?			
o Congealing?			
o Segregation?			
o Cold Flow?			
o Fracture?			
THERMAL ENVIRONMENT			
7. Have the expected temperature variations per unit time -- both thermal shock and ambient temperature versus altitude -- been investigated and considered in the design?			
8. Does such protection provide for:			
o Incidental leaking of coolant, lubricant or any other fluid heat-conveying medium?			
o Local effect of a heater or heat-source, such as hot-spots, focal points, or unintentional reflection?			
9. Is the equipment either free of or protected against:			
o Chemical corrosion (reactive processes)?			
o Thermal corrosion (heat fatigue)?			
10. Have provisions been made to ensure equipment success even if limited corrosion or leakage of materials used in the equipment should occur?			
11. Have thermal stresses and differential thermal expansion been considered?			

	ADEQUATE	INADEQUATE	N/A
12. Are polished and unpainted radiation shields provided to protect heat-sensitive parts from "seeing" hot parts?			
PRESSURE ENVIRONMENT			
13. Has the pressure environment to be encountered by the equipment, both operating & non-operating, been considered?			
14. Have all materials used in the design - especially plastic laminates or coatings - been checked for out-gassing and generation of arc-sustaining atmosphere?			
15. Have the diaphragm strengths of the various mechanical assemblies and packages been checked for adequacy where pressure differentials may exist?			
16. In space equipment, have possible explosive decompressions been avoided by adequate outlet areas?			
17. Has the sublimation of materials been considered in the system design and in application of:			
o Package surfaces and containers?			
o Insulators and wiring?			
o Hardware and fastening materials?			
o Surface platings and coatings?			
o Lubricants, where premature evaporation might occur?			
HUMIDITY			
18. Have the worst expected humidity environment and the time in the environment been investigated (both operating and non-operating?			

	ADE-QUATE	INADE-QUATE	N/A
19. Where high-humidity and condensation are to be encountered, has the design:			
o Protected component boards by application of conformal plastic coatings or equivalent moisture barrier?			
o Protected RF components & waveguides by sealing wherever possible?			
o Protected appearances and utility of cabinet or container surfaces and fastenings by application of moisture resistant platings or coatings?			
o Protected grounding and bonding continuity by overcoating and sealing of ground lug and fastener assemblies?			
o Protected cables and interconnection wiring by suitable potting or encapsulation of connectors and by choice of moisture resistant connectors?			
o Generally provided against loosely overlapping sheet metal surfaces, folds, tucks, and other unnecessary moisture entrapment points?			
20. Have the relative moisture absorption characteristics of insulators or insulating bonds in electronic components been evaluated?			
21. In general, have hermetically sealed or encapsulated parts been chosen wherever possible to reduce humidity-induced variation of part parameters?			
MECHANICAL SHOCK AND VIBRATION			
22. Have the expected mechanical environmental stresses been specified or estimated in terms of:			
o Amplitude and approximate waveforms of shock inputs (equivalent pulse rise, dwell, and decay)?			

	ADE-QUATE	INADE-QUATE	N/A
o Amplitudes, accelerations, and frequency ranges of vibration inputs (fixed frequencies or random inputs, wide or narrow band)?			
23. Have the principal dynamic stresses on the package or functional assembly been calculated, or has an accurate model been tested with proper and sufficient instrumentation?			
24. Has at least a static stress analysis, using acceleration levels appropriate to the expected dynamic loading and including specified margins of safety been prepared for the package or assembly?			
25. Have all fasteners and hold-down devices been checked for adequacy under maximum shock loading?			
26. Have chassis and sidewall configurations been designed to provide minimum amplification paths for vibration excitation of part mountings and component boards?			
27. Have statistically meaningful samples of all electronic component parts been qualified in mechanical environments similar to those expected in service (operating and non-operating)?			
28. Have the fundamental resonant frequency of all component boards been checked and maintained as high as feasible to limit vibration deflection and resulting stress on parts and wiring?			
29. Have component board resonant frequency been raised by increasing stiffness through size reduction, additional thickness, addition of supports, addition of edge-beam stiffeners, and/or choice of high-specific-damping materials?			
30. Have isolators or "soft" mounting been investigated for use where part sensitivites to the mechanical environment may be a source of unreliability?			

	ADE-QUATE	INADE-QUATE	N/A
31. Have the characteristics of isolator materials been checked or tested over the entire expected vibration range, and have the effects of steady acceleration on these materials been checked?			
32. Have the total time in the mechanical environment and the possible equipment fatigue results from repeated cycles and/or repeated stresses (S-N curve evaluation) been considered?			
33. In general, for electronic component-part assemblies, have the designs attempted to isolate or minimize amplifications of the vibration inputs so that maximum accelerations on parts do not exceed specification limits?			
RADIATION ENVIRONMENTS			
34. If radiation environments are to be encountered, have the different types of radiation (electromagnetic corpuscular) been considered, and has the exposure time in each been estimated?			
35. For space equipment:			
o Have the effects of solar, ultraviolet, cosmic and Van Allen belt radiations been considered?			
o Have skin shields such as aluminum, magnesium, plexiglass, fiberglass, etc. been applied against ionizing radiation, and have solar cells been protected with cover glass or the equivalent?			
o Where corpuscular radiation causing secondary emission will be encountered, has additional shielding (heavier aluminum or copper) been provided or has skin shielding been followed by local shielding of sensitive parts?			

	ADE-QUATE	INADE-QUATE	N/A
o Is the shielding design capable of stopping or adequately reducing expected proton, electron, gamma, and X-radiation?			
o Have radiation resisting component parts - such as wirewound, carbon-film, and metal-film resistors, ceramic and glass capacitors, and thin base transistors - been used?			
o If radiation-sensitive parts must be used (for example: diodes and some transistors), have adequated shielding precautions been taken?			
MISCELLANEOUS ENVIRONMENTS			
36. If sand and dust are to be encountered, are equipment enclosures, control panels and connector panels adequately sealed; have open corners been eliminated; and have cooling-air inlets been adequately filtered?			
37. If salt water or corrosive atmospheres are to be encountered, have paint finishes & platings that will withstand the exposure been used, or have non-corrosive metals been applied in the design?			
38. Where conditions to be encountered will support fungus growth, have fungus-nutrient materials been eliminated from the design?			

8.0 ELECTROSTATIC DISCHARGE (ESD)

Many parts can be damaged by electrostatic discharge (ESD) and must be protected during the manufacturing process and even after delivery of the complete equipment, particularly spare printed circuit boards.

	ADE-QUATE	INADE-QUATE	N/A
1. Do the drawings identify ESD devices so that all personnel involved (receiving, manufacturing, assembly, test, etc.) realize that ESD devices are being used and must be protected?			
2. If DOD-STD-1686 applies, have circuits been divided into Class 1, 2, and 3:			
o Has use of Class 1 parts been minimized?			
o Have protective circuits been used to limit assembly sensitivity to Class 2 minimum?			
o If protective circuitry can not be used, has appiovedal of the aquiring activity been obtained?			

ESD CONTROL PROGRAM - SURVEY CHECKLIST

FUNCTION	RESPONSIBILITY	ADEQUATE	
		YES	NO
Engineering/ Design Services	1. Is protective circuitry incorporated at the lowest practicable assembly level to protect sensitive ESDS items at the assembly and equipment levels?		
	2. Do all drawings of ESDS ems identify the item as ESDS; are they marked with sensitive electronic device sysmbol of Mil-STD-129 and ESD caution; do they reference applicable ESD precautionary procedures; and do they identify the sensitive pins or terminals of assemblies and equipment?		
	3. Do the drawings show the requirements for proper ESD marking of ESDS assemblies and equipment located so that it can be readily seen by maintenance personnel prior to removing/replacing the ESDS item?		

ESD CONTROL PROGRAM - SURVEY CHECKLIST

FUNCTION	RESPONSIBILITY	ADEQUATE	
		YES	NO
Equipment/ System Test and Integration	1. Is testing performed in ESD protected areas which limit static voltages to 4000 volts or less?		
	2. Are ESD precautionary procedures provided for personnel who install ESDS equipment?		
	3. Are ESDS items enclosed in ESD protective covering prior to transfer out of the ESD protected area?		

ESD CONTROL PROGRAM - SURVEY CHECKLIST

FUNCTION	RESPONSIBILITY	ADEQUATE	
		YES	NO
Production: Receiving Inspection	1. Is the receiving area equipped as an ESD protective area where packages of ESDS items are opened?		
	2. Are ESD precautionary procedures provided for personnel who handle ESDS items out of their protective packaging?		
	3. Are ESDS items identified on shipping documents and labeled as ESDS by the supplier?		
	4. Are ESDS items removed from their ESD protective packaging for inspection or test, repackaged in ESD protective material after inspection?		
Processing, Assembly, Inspection, Repair and Rework	1. Is all processing machinery properly grounded or equipped with ionizers or other means to limit static to safe levels?		
	2. Are carts or wagons used to transport ESDS items throughout the plant equipped with conductive wheels to control the buildup of unsafe static charges?		
	3. Are all part carriers (tote boxes/ trays, etc.) used to transport ESDS items made of ESD protective (preferably conductive) materials?		
	4. Are ESD precautionary procedures provided for all personnel who handle ESDS items during the production operation?		
	5. Are ESDS items enclosed in ESD protective covering material after completion of assembly and test?		

ESD CONTROL PROGRAM - SURVEY CHECKLIST

FUNCTION	RESPONSIBILITY	ADEQUATE	
		YES	NO
Packaging and Shipping	1. Is handling and packaging performed in ESD protected areas?		
	2. Are ESD precautionary handling and packaging procedures provided for personnel who package the ESDS item(s) for delivery?		
	3. Does packaging provide protection against:		
	a. Triboelectric generation?		
	b. Direct discharge from a charged person or object?		
	c. Electrostatic fields?		
	4. Are packaging containers properly marked with the MIL-STD-129 electronic device sensitive symbol and ESD caution?		

ESD CONTROL PROGRAM - SURVEY CHECKLIST

FUNCTION	RESPONSIBILITY	ADEQUATE	
		YES	NO
Quality Assurance/ Reliability	1. Are all inspection areas where ESDS items are handled, inspected or tested, ESD protected?		
	2. Are ESD precautionary procedures provided for all quality functions and documented in the contractor's quality assurance manual?		
	3. Are failure analysis laboratories equipped with ESD protected areas?		

APPENDIX B

MAINTAINABILITY CHECKLIST

MAINTAINABILITY CHECKLIST SECTIONS

1.0 CONCEPT DEFINITION

	ADE-QUATE	INADE-QUATE	N/A
1. Simple systems (<2000 parts) are better not tested. The inhertent reliability of simple dormant systems is apt to be more harmed than improved by periodic testing. If the system design is simple, would it be best to treat the system as a "wooden round" and have no periodic maintenance requirements?			
2. Have calculations of the expected operating and non-operating MTBF for the given system been made?			
3. If the complex system inherent low reliability will most likely result in a periodic monitoring/repair maintenance concept, has the optimum periodic monitoring frequency been determined? (Note - Early dormant systems were often tested to failure and overhauled to death. Experience has shown that reducing the number of tests and inspections often results in improved reliability.)			
4. Is the selected maintenance concept compatible with the system's mission and deployment requirements?			

2.0 GENERAL DESIGN CRITERIA

	ADE-QUATE	INADE-QUATE	N/A
1. If a "wooden round" maintenance concept has been chosen, have the following factors been considered in the design:			
o Use of 100% burn-in, screening and preconditioning of parts or subsystems, on both electronic and mechanical items.			
o Avoidance of storage-time-critical components and materials.			
o The system should be designed for simplicity using a minimum of parts.			
o Use of an inert atmosphere (such as nitrogen).			
o Use of transport and storage containers as tactical packaging to mitigate the effects of long-term exposure to life cycle environments.			
o Interconnection plugs should only be used if no other design is available.			
o Reduction to a minimum of built-in test points for external testing as they are unnecessary and may provide paths for moisture and contamination intrusion.			
o Use of compact structure, combining PC boards and sealing the system.			
o Use of digital electronics with no field adjustment.			
o Manufacturing and quality assurance methods to increase reliability, through increased usage of automatic test equipment during manufacture.			
o Complete documentation of manufacturing parameters and test results.			
o If necessary, incorporation of redundancies.			
o Replacement of parts which, due to their present technology, are time change items. This should be accomplished without any disassembly or test, and the system should remain in its container. Replacement of modules should be limited to the smallest possible individual element.			

3.0 FAULT INDICATORS

	ADE-QUATE	INADE-QUATE	N/A
1. Have direct fault indications been provided? (This means that either a fault light or an audio signal is provided or there is a direct indication of a malfunction through a meter reading or similar means.)			

4.0 ADJUSTMENTS

	ADE-QUATE	INADE-QUATE	N/A
1. Are positive locking devices provided to assure retention of settings of adjustments or alignment devices that are susceptible to vibration or shock?			

5.0 CONSOLES, CASES AND COVERS

	ADE-QUATE	INADE-QUATE	N/A
1. Is the base of each console reinforced to enable lifting with a forklift truck?			
2. Are connectors and other parts which normally extend beyond outside covers or cases recessed or adequately protected by some other means?			
3. Are weight labels provided on each rack and console?			
4. Are cases made enough larger than the units they cover, so that wires and other components are not likely to be damaged when the cases are put on and taken off?			
5. Are guides and tracks provided to help prevent cases from cocking to one side and causing damage?			
6. When the edges of a case must be slid over rubber stripping or other sealing material, is the sealing material adhered tightly enough so that it does not buckle or tear, damaging the seal or jamming the case?			

6.0 PACKAGING

	ADE-QUATE	INADE-QUATE	N/A
1. Does the overall packaging concept allow the removal of a replaceable assembly or part without removing any other?			
2. Have guide pins been provided to facilitate installation of plug-in units?			
3. Are plug-in units keyed (by some means other than the connector) to prevent accidental insertion in the wrong location?			
4. Does all equipment containing synchros, electrical resolvers, servo motors, slip rings, and other delicate electrical rotating equipment, delicate ball bearings, or high precision gears, cams and levers have a dust-tight enclosure or are these items in dust-tight sections of the equipment?			
5. Are units light enough for ease of removal? Have adequate handling devices been provided?			
6. Is each assembly self-supporting in the desirable position or positions for maintenance?			
7. Can assemblies be laid on a bench in any position without damaging components?			
8. Are guards or other protection provided for easily damaged conductors such as waveguides, high frequency cables, or insulated high voltage cables?			
9. Can irregular extensions such as bolts, cables, wave guides, and hoses be easily removed before the unit is handle? Such protrusions are easily damaged and make handling difficult.			

7.0 EXTERNAL ACCESS

	ADE-QUATE	INADE-QUATE	N/A
1. Are access openings without covers used where this is not likely to degrade performance?			
2. Is a transparent window or quick-opening metal cover used for visual inspection accesses? Are humidity indicators clearly visible from outside the container or package?			
3. Are panels, covers, access doors, etc., secured to the equipment by means of fastening devices such as captive spring bolts or screws, trunk fasteners, dogs, levers, and latches, in order to provide quick and easy access to the interiors of those portions of the equipment?			
4. Have the same size and type of fasteners been used for covers and cases on a given equipment where practicable? Quick-acting fasteners are recommeded for dust covers. Fine threaded screws are recommended for pressurized units.			
5. Are environmental factors (cold weather, darkness, etc.) considered in design and location of all manipulatible items of equipment?			

8.0 LUBRICANTS

	ADE-QUATE	INADE-QUATE	N/A
1. Is the type of lubricant to be used and the frequency of lubrication specified by a label at/near the lubrication port?			
2. Have the adverse effects of lubricants, fuels, and fluids during dormant storage been investigated and have suitable measures been taken to mitigate them?			

9.0 TOOLS

	ADE-QUATE	INADE-QUATE	N/A
1. Is the equipment accompanied by a comprehensive list of tools needed for all maintenance tasks?			
2. Have tools been specified to cover all maintenance procedures?			
3. Do fasteners for chassis and panels require special tools?			
4. If special tools are required have they been provided with the equipment?			
5. Are each of the provided tools adequate for efficient performance of maintenance jobs?			
6. Are tools which must be used near high voltages adequately insulated at the handles and other parts of the tools which the technician is likely to touch?			
7. Are screwdrivers provided which have clips to hold free screws which cannot be easily held with the fingers?			

10.0 LABELLING

	ADE-QUATE	INADE-QUATE	N/A
1. Are labels placed for full, unobstructed view?			
2. Does displayed printed matter always appear upright to the technician from his normal viewing position?			
3. Are display labels imprinted, embossed, or attached in such a way they will not be lost, mutilated, or become otherwise unreadable?			
4. When parts MUST be replaced at specified intervals, are they clearly marked?			
5. On equipment utilizing color coding, is the meaning of colors given in manuals and on an equipment panel?			

APPENDIX C

TESTABILITY CHECKLIST

TESTABILITY CHECKLIST SECTIONS

1.0 CONCEPT DEFINITION

	ADE-QUATE	INADE-QUATE	N/A
1. If a "wooded round" maintenance concept has been chosen, does the testability concept support its objectives? o Simplicity of design o Minimization of parts to maximize reliability o Elimination of paths for moisture or contamination intrusion o No checkout before use o Maintenance free storage			
2. If a Periodic Monitoring/Repair maintenance concept has been chosen, does the testability concept support it objectives?			
3. Does the testability concept appropriately address stockpile testing requirements?			
4. Does the testability concept minimize "on" time to avoid degrading reliability?			
5. Does the testability concept minimize the possibility of test induced failures or equipment degredation?			
6. Does the testability concept provide for the retention of the maximum amount of test parameter data for failure prognosis and trend analysis?			

2.0 ELECTRICAL DESIGN FOR TESTABILITY

	ADE-QUATE	INADE-QUATE	N/A
1. Have the following been considered to make maintenance easier:			
o Units should be able to be checked independently?			
o Group the circuits so that a minimum of crisscrossing of signal units is required?			
o Modules should have as few input and output signals as possible?			
o Avoid "trick" or extremely sensitive circuitry; use standard circuits?			
o Separate operational circuitry from maintenance circuitry?			
o Design for maximum use of maintenance aids (troubleshooting procedures, maintenance diagrams, and circuit data)?			
o Design maintenance procedures concurrent with equipment design?			
2. Has consideration been given towards isolating trouble areas without complete equipment power up?			
3. Are testing, alignment, and repair procedures such that a minimum of knowledge is required on the part of maintenance personnel? Can trouble shooting of an assembly take place without removing it from a major unit?			
4. Is the design such that no unrealistic requirements for special facilities for maintenance, storage. or shipment are imposed?			
5. Is the design such that no unnecessary requirements for a special maintenance environment (e.g., ground power carts, cooling, special primary power, etc,) are imposed?			

	ADE- QUATE	INADE- QUATE	N/A
6. Are components that are designed to respond to environmental stimulae easily disconnected so that they can be connected to simulators for individual testing?			

3.0 TEST POINTS

	ADE-QUATE	INADE-QUATE	N/A
1. Are all test points placed or guarded so that the technician is physically prevented from contacting high voltage?			
2. Are test points accessible in the particular installation?			
3. Are there test points available for the direct check of all replaceable parts?			
4. Are routine test points provided which are available to the technician without removing the chassis from the cabinet?			
5. If unstable components can be identified or expected in equipment, are check and adjustment points available and convenient for checking them?			
6. Are test points connected so that no damage to the system can occur by introduction of an incorrect signal?			
7. Are test points compatible with planned test equipment?			
8. Are built-in test features provided wherever standard portable test equipment cannot be used.			
9. Have adequate precautions been taken to prevent test points from providing a path for moisture and contamination intrusion in the equipment?			

4.0 TERMINALS

	ADE-QUATE	INADE-QUATE	N/A
1. Are terminal strips and standoffs located and labeled so that they can serve as convenient check points while the equipment is in operation?			
2. Are terminal strips mounted so as to be accessible from the front of the equipment when opened?			
3. Unless otherwise specified, are all external cables and interconnecting harnesses used to connect major units of sets or systems, terminated on barrier type terminal strips?			
4. Are terminal strips located in positions which will best facilitate testing of the equipment?			

APPENDIX D

LIST OF ACRONYMS

List of Acronyms

TERM	DEFINITION
ac	Alternating Current
AFSC	Air Force System Command
AG	Availability Guarantee
ALT	Accelerated Life Testing
ATE	Automatic Test Equipment
AUR	All-Up-Round
BIT	Built-In-Test
BTU	British Thermal Units
CBS	Cost Breakdown Structure
CCG	Captive Carry Guarantee
CERT	Combined Environments Reliability Test
CMOS	Complementary Metal Oxide Semiconductor
COD	Correction Of Deficiencies
CODSIA	Council of Defense and Space Industries Association
CPFF	Cost Plus Fixed Fee
dB	Decibels
dc	Direct Current
DH	Design Handbook
DoD	Department of Defense
DSS	Decision Support System
ECAP	Electronic Circuit Analysis Program
ECP	Engineering Change Proposal
EMP	Electromagnetic Pulse
ESS	Environmental Stress Screening
FSD	Full-Scale Development
GFE	Government Furnished Equipment
GN2	Gaseous Nitrogen
IA	Incentive Award
ILS	Integrated Logistic Support
LCC	Life Cycle Cost
LEC	Lockheed Electronics Company, Inc.

List of Acronyms

TERM	DEFINITION
LL	Lower Limit
LRU	Line Replaceable Unit
LSI	Large Scale Integration
LTPD	Lot Tolerance Percent Defective
MDG	Mission Dependability Guarantee
MDT	Mean Down Time
MIL	Military
MIL-HDBK	Military Handbook
MIL-STD	Military Standard
MOS	Metal Oxide Semiconductor
mph	Miles Per Hour
MSI	Medium Scale Integration
MTBF	Mean Time Between Failure
MTBMA	Mean Time Between Maintenance Actions
NPV	Net Present Value
O&M	Operation and Maintenance
O&S	Operation and Support
PAWS	Platoon Early Warning System
PEDs	Plastic Encapsulated Devices
PERT/CPM	Program Evaluation Review Technique/Critical Path Method
PIND	Particle Impact Noise Detection
PPA	Product Performance Agreement
psi	Pounds Per Square Inch
PSM	PPA Selection Matrix
QPL	Qualified Parts List
R&M	Reliability and Maintainability
RADC	Rome Air Development Center
RIW	Reliability Improvement Warranty

List of Acronyms

TERM	DEFINITION
SCEPTRE	Systems for Circuit Evaluation and Prediction of Transient Radiation Effects
SRU	Ship Replaceable Unit
SSI	Small Scale Integration
SVG	Storage Verification Guarantee
TREE	Transient Radiation Effects on Electronics
TRMF	Theater Readiness Monitoring Facility
UL	Upper Limit
VHSIC	Very High Speed Integrated Circuit
VLSI	Very Large Scale Integration